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CONFIDENTIAL

25X1

December 3, 1957

Dear Sir:

This letter report describes the research conducted under Task Order No. Q from October 1 through November 4, 1957. This report presents in some detail a summary of the information obtained and the results of a cursory evaluation.

SUMMARY

The literature has cited the installation of a sewer in Canada that has dimensions which can be considered to be within the limits specified under Task Order No. Q for a horizontal hole. This sewer was constructed of precast-concrete rings having a 36-inch-equivalent elliptical cross section, and involved tunneling for a distance of 2,300 feet. To be directly applicable to the objective of Task Order No. Q, such an operation would have to be preceded by a topographical survey; the line and grade of a tunnel would be determined by conventional surveying means, and the depth below the surface could be established only after the topography of the area was determined.

Also, additional information was obtained on 4 more of the original 18 methods of excavating holes. Turbodrills are on the verge of becoming available from Dresser Industries. A horizontal

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auger is reported to have bored for a distance of 530 feet. One of the Consolidated Edison Company of New York machines has made a horizontal bore 340 feet long, missing the target by only 2 feet. A commercial machine patterned after the drill designed by the California Division of Highways is now on the market. Thus, the possibility of applying one of these four methods to the excavation of interest has improved, but there is still no evidence that a similar excavation has been accomplished by any one of them.

A further study of deep-well practices with regard to the use of drilling mud and the casing of bore holes has disclosed favorable possibilities. The use of steel well-casing installed in steps of reduced diameter might enable an existing machine, such as a heavy-duty horizontal auger, to make the proposed length of bore. The other possibility is to pressurize the excavation with drilling mud. Keeping a horizontal hole filled and pressurized with drilling mud might eliminate the need for a liner and also improve the possibility of using a horizontal rotary drill or a pipe-boring machine like that of Consolidated Edison Company of New York.

A magazine article printed in 1947 describes a horizontal-drilling system proposed by Leo Ranney. His objective was remarkably similar to that of Task Order No. 9. There is no indication as to whether Ranney's system was ever tried.

No further information was obtained on the subjects of overburden penetration and unusual drilling methods. No proven methods of detecting or controlling the direction of a horizontal drill have

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been noted. These latter factors, detecting and controlling, apparently are the least-developed phases of horizontal drilling.

Future work on Task Order No. 3 will be devoted to a more thorough evaluation of the information at hand, and the preparation of a summary report on the research program.

ENGINEERING ACTIVITY

The project activity during October has been a continuation of the search for information on excavating and lining long horizontal holes. The subjects of overburden-penetration methods and unusual drilling methods were of particular interest. Some additional information on a few of the more promising drilling methods previously reported has been obtained from organizations concerned with them.

A patent art search was also conducted in October. Copies of approximately 100 patents were obtained on a variety of devices and machines pertaining to earth boring and drilling, and mining. A great many ideas are represented therein; some of these contribute very little to the present study, but could be of value to a development program directed toward achieving the objectives of Task Order No. 3.

The results of our continued search are presented in the following sections, which are similar to those of the last report (dated October 30, 1957). The items on which no additional information was found are omitted.

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Methods of Excavating Holes

Additional information has been obtained on 5 of the 18 methods of excavating holes indicated in the last report. These five methods, with their original item numbers, are as follows:

(2) Vertical down-hole rotary drilling

(9) Horizontal auger drilling

(12) Horizontal pipe-boring

(16) Horizontal rotary drilling

(18) Tunneling.

Vertical Down-Hole Rotary Drilling

An inquiry was made of Dresser Industries, Inc., Dallas, Texas, to determine the current situation with regard to turbo-drill availability. Mr. Mitchel of that organization said that they plan to market turbodrills on a very limited basis within the next month or two. They will fabricate the drills to be marketed.

This promise of availability carries with it only the connotation that turbodrills could definitely be considered in a horizontal-drilling-unit development program, if such a program should come about. A turbodrill is still not directly applicable to horizontal drilling through earth.

Horizontal Auger Drilling

Some interesting information was provided by Mr. T. S. Henry, Assistant General Manager of Ka-Mo Tools, Inc., Cicero, Illinois,

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which makes and markets horizontal earth-auger machines. Mr. Henry said that the nominal maximum bore length for a horizontal auger is usually limited by the drive-motor torque. Air motors are the usual power source provided as part of Ka-Mo augers. It has been found practical in some instances to modify the auger machines by using two air motors in tandem, thus supplying greater torque and facilitating a longer bore. A large electric motor or a gasoline engine can be used in place of the air motors if still greater torque is required. He recalled one case in which a bore 36 inches in diameter and 530 feet long was made with an auger working inside of a steel pipe; the power supply in this case was two gasoline engines.

There is, of course, a limit to the practicability of increasing the power supply or torque on existing augers, as Mr. Henry pointed out. An excessive increase in torque would simply result in an auger failing in torsion. He said that they had not had occasion to build an extra-strong auger with a 6 or 8-inch diameter, but he indicated that they would be interested if there were a potential market for such an auger.

The accuracy of auger bores was also discussed briefly with Mr. Henry. Apparently, the skill of the operator can influence the straightness of bore almost as much as can the consistency of the various types of materials encountered. For any given soil condition, there seems to be an optimum combination of rotational and feed rates which will result in the straightest hole. Only by the application of the operator's experience and skill can this combination be

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approached with any degree of dependability during actual excavation. Mr. Henry said that operation of a horizontal auger inside of a pipe or hole liner also improves the hole straightness. Advancing the pipe along with the auger provides a continuous stiffening effect and thus reduces hole deviation.

Horizontal Pipe-Boring

Mr. John Bogdanowski, Superintendent of the Methods Division, Consolidated Edison Company of New York, provided a little more information on their experience with the special pipe-boring machines. A telephone conversation with him and a recently published article(25)* on a paper written by him were the bases for obtaining this additional information.

The longest bore achieved so far by the pipe-boring technique is 340 feet. The diameter of this bore was not mentioned, but is assumed to be at least 16 inches. In this particular case, a railroad embankment consisting of boulders, gravel, and clay was bored. The termination of the bore missed the target by only 2 feet.

These Consolidated Edison machines - three sizes are in use - have been found by that company to be quite satisfactory. The machines, especially the smaller sizes, are utilized almost daily.

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*Numbers in parentheses refer to items listed in the Bibliography; the numbers of the references in this report follow consecutively those listed in the previous report (dated October 30, 1957).

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and interested persons could see one in operation at almost any time, after appropriate arrangements were made.

<u>Horizontal Rotary Drilling</u>

The literature reference on the horizontal drill prepared and used by the California Division of Highways, that was cited in the last report as Reference 21, was about 2 years old. Mr. A. W. Root, Materials and Research (Div.) of that organization, was contacted to obtain information about their subsequent experience with the drill rig, which involved conventional rotary drill bits and drill string or rod, and had the capability of thrusting casing into the drilled hole.

Three or four of these horizontal drills have been in use intermittently during the past two years or so. The maximum hole diameter bored is still 4-1/2 inches, and the maximum bore length is still about 300 feet.

Mr. Root said that they do experience hole deviations and that the skill of the operator is depended upon to keep deviations to a minimum. This is explained in a later section of this report under "Directional Control". Mr. Root confirmed the assumption made in our last report, that an area of subsurface water is a relatively large target, and consequently, in attempts to intercept such a target, some hole deviation can be tolerated.

The application of these drills is exclusively for boring holes into which a 2-inch-diameter drain pipe is inserted. Mr. Root

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indicated that they occasionally have serious difficulty with drain-pipe insertion after drilling because of cave-ins. Such caving in, however, does not seem to bother the drilling operation or drill removal.

It was also learned from the discussion with Mr. Root that a manufacturer in Oklahoma has just recently placed on the market a drill patterned after the California machine. That manufacturer was subsequently contacted and has provided advertising literature.

Tunneling

One reference was found to literature which describes a special kind of tunnel sewer construction(26). The size of sewer and the method of construction are within the scope of interests of Task Order No. 3.

The unique feature of this method is the use of elliptical, precast-concrete, liner rings. These rings are quite short axially, and this feature permits them to be passed through each other. For example, the first liner ring is set in place at the tunnel entrance (the major axis of the ellipse is set vertically). The tunnel is excavated a few feet beyond the set ring. The second liner ring is laid on its peripheral side, is passed through the first ring, and is erected by hand and joined with the first ring, thus extending the liner inward. As tunneling progresses, the transportation of liner rings is accomplished by the use of a small, electrically powered machine which runs on a track. This same machine is used to haul mucking carts back to the tunnel entrance.

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Sanitized Copy Approved for Release 2011/06/28 : CIA-RDP78-03642A002400070001-7

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The concrete liner rings comprise the final structure, thus eliminating the need for a temporary liner or for the forms and bracing which would be necessary if the structure were to be of monolithic concrete. For tunneling in earth which is not self supporting, it is claimed that a shield can be jacked ahead in the conventional manner, to provide worker protection during excavation and ring erection.

The literature cites three cases in Canada where this method of tunnel sewer construction has been applied. In one of these cases, a section of "36-inch-equivalent sewer" was 2,300 feet long; it is assumed that the capacity or cross-sectional area of the elliptical sewer was equal to that of a 36-inch circular pipe. With manual excavation, a 36-inch-equivalent elliptical hole, with the major axis of the ellipse vertical, would be more easily tunneled than a 36-inch circular hole because in the elliptical tunnel, the workers could operate in a more upright position.

Hole Locating

Additional information was requested from, and supplied by, Mr. Steven Gurasich of Sperry-Sun Well Surveying Company on their pipe-line surveying instrument. The information reported previously mentioned a 16-inch pipe as the smallest-size pipe surveyed. To learn definitely the minimum size of pipe that could be surveyed was the primary reason for requesting further information.

Sperry-Sun has done no pipe-line surveys for some months. It seems that there was a definite need for an instrument smaller than

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the mole used previously in 16 to 30-inch pipe. They attempted to provide a smaller instrument by using a smaller gyroscope. The smaller gyroscope, however, did not provide directional information of sufficient accuracy, and, as a result, the pipe-line surveying service was shelved by this organization.

The existing mole will enter a pipe with a minimum diameter of about 10 inches. The minimum diameter of pipe that can be surveyed, they estimate, is in the order of 14 inches; the mole is approximately 6 feet long and the operators desire ample clearance to assure that the unit will traverse bends in the pipe.

On two occasions, Sperry-Sun found it necessary to use an electrically powered crawler to propel the mole through a pipe line. Both times the crawler was supplied by Industrial Exray of Houston, Texas. Such a crawler could conceivably be a suitable means for running a surveying instrument into a horizontal hole in the earth.

The surveying mole is not a marketed item. However, Sperry-Sun in the past has provided quotations for leasing the unit. Mr. Gurasich was unable to estimate the current position of Sperry-Sun with regard to leasing or selling one of the devices.

It was interesting to note a method and device proposed in a patent(27) for transmitting orientation information from a down-hole wedge or whipstock to ground surface. The inventors claim that the device will signal to the drill operators when a whipstock or similar tool is facing the desired direction, after the whipstock has been

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lowered to the proper depth. It is further claimed that the device can also be made to indicate the inclination of the bore hole at the location of the whipstock.

The signal transmitter of this unit is a battery-powered electronic device which is enclosed in the whipstock. It is claimed that the signals are conducted along the drill string, thus eliminating the need for wires and also precluding the loss of the signals to the surrounding earth. Such a device would not have to be withdrawn from the hole prior to continued drilling.

The orientation method described by the inventors is for static positioning. Although it has no immediate application to the problem of Task Order No. Q, the idea might have considerable value to the development of suitable tools and methods.

Directional Control

As was mentioned earlier in this report under "Horizontal Rotary Drilling", the California Department of Highways has found that they can exercise some control over the vertical deviation of their special horizontal drilling rig. This control is provided by the drill operators and is a reflection of the rate at which the drill is pushed longitudinally into the earth. The operators have found that a high feed rate causes the drill to deviate upward, and a low feed rate causes downward deviation. However, only an individual operator's personal "feel" of a particular situation can tell him whether the feed rate is high or low.

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A very interesting magazine article[28] has been noted that describes a proposed method of drilling long horizontal holes in the earth. The article is about Leo Ranney, a geologist and one-time engineer in the petroleum industry, and the same man who founded Ranney Method Water Supplies, Inc. Ranney envisioned a method of drilling long, controlled-direction, horizontal holes, an objective having a remarkable similarity to the interests of Task Order No. Q. His proposed method appears to be a horizontal application of the oil-well drill-string technique. The article was published in 1947, and we have no information as to whether Ranney ever tried the method or secured any patent protection for it. The article was located subsequent to our patent search.

Ranney proposed to take advantage of the facts that, when drill string is used, the drill bit is larger in diameter than the string, and that a relatively long section of drill string is heavy and somewhat flexible. He guessed that the normal tendency for the drill string to sag to the bottom of a horizontal hole would cause the drill bit on the end to tip upward and therefore drill at an upward inclination. For straight drilling, he proposed the use of a length of collar, almost as large in diameter as the bit and located immediately behind the bit, to stiffen the string and overcome the effect of drill-string sag. To incline the drill downward, he intended to use two short collars, one located close to the bit and the other a few feet farther back. The sagging of the drill string located rearward to the second collar was supposed to cause the section of string between the collars to bow upward; thus, the bit would be

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inclined downward. Horizontal control was to be accomplished by some kind of a crawler located adjacent to the drill bit, but the article did not describe this device.

Of course, the Ranney method of horizontal drilling is of little value to Task Order No. Q at present. The coincidence of objectives, though, and the fact that Ranney was experienced in various kinds of well drilling make the method noteworthy.

Hole Lining

The additional information obtained points out that an oil or gas well is cased for its full depth upon completion of the drilling process[29]. The casing makes the bore hole a permanent hole for the production of oil or gas. It is the method of casing a deep well that is considered pertinent to the Task Order No. Q problem.

Apparently, it is customary, or at least common practice, to drill a deep well in a stepped manner, i.e., the beginning portion of a bore hole is made large in diameter as compared to the anticipated final diameter of the hole which will enter the oil or gas-bearing formation. How deep the hole of largest diameter is drilled is determined by a number of factors, one of which is how far casing of appropriate size can be driven. Beyond this depth, the bore hole is smaller in diameter, and casing for this portion can pass through the casing already driven. This procedure can be repeated as many times as may be necessary either to facilitate further drilling or to complete the well for production.

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We have previously reported indications that pipe can be pushed horizontally through earth for a distance of only a few hundred feet. The "step" procedure, then, might well provide the means of lining with steel a horizontal hole 2,400 feet long. In the application of this technique, a liner of each size would extend from the hole entrance into the earth, but would be in direct contact with the earth only for the distance of the few hundred feet through which it could be jacked.

Another suggestion can be taken from deep-well drilling practice using drilling mud. It was discussed briefly, in the last report, how drilling mud can produce the effect of a liner by plastering loose materials together. However, it seems that the effect of drilling mud goes beyond this, particularly in deep holes. The high hydrostatic pressure created by the column of mud is often the means of preventing lower portions of the hole from caving in, or of preventing water or gas from entering the hole. It is conceivable that the same benefits could be realized in a horizontal bore by substituting pump pressure for columnar pressure. This would require a stuffing box of some kind around the drill string at the hole entrance. Depending upon the ultimate use of the hole, such a pressurized bore might not have to be lined. For example, if the intended use were for the installation of an instrument at the end of the hole with connecting wires leading back to the hole entrance, installation could occur immediately after drilling. The instrument could conceivably be placed on the end of the drill string

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and pushed through the mud into the desired position. Under these conditions, the instrument, drill string, and mud could all remain in place.

FUTURE WORK

The completion of the research herein reported terminates our search for new information. Future work on Task Order No. 3 will consist of an over-all evaluation of the available information and the preparation of a summary report.

The original appropriation on this Task Order was $5,300. As of November 1, 1957, the unexpended balance was approximately $1,570.

Sincerely,

[redacted] 25X1

ABW:mjo

In [redacted]

25X1

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27. Goble, R. W., and Jackson, G., "Methods of and Apparatus for Transmitting Intelligence to the Surface From Well Bores", U. S. Patent 2,492,794 (December 27, 1949). Assigned to Eastman Oil Well Survey Company.

28. "Horizontal Drilling", Fortune, 36, 96-101 (September, 1947).

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*The reference numbers in this report follow those of the last report (dated October 30, 1957) consecutively.

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[redacted]

25X1

November 26, 1957

EB-175 L

Dear Sir:

Task Order No. Q

Enclosed are duplicate copies of four more articles that are of general interest in connection with the activity under this Task Order.

Sincerely,

[redacted] 25X1

ABW:mjc

In Duplicate

Enclosures (4, in duplicate)

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Warren

25X1

October 10, 1957

Rec'd ED 10/15/57 1600

Dear Sir:

Task Order No. Q

Enclosed are duplicate copies of seven more articles, and of the 1956 and 1957 special issues of a pertinent journal, that are of general interest in connection with the activity under this Task Order.

Sincerely,

25X1

ABW:dp

In Duplicate

Enclosures (9, in dupl)

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[redacted] 25X1

September 25, 1957

Dear Sir:

<u>Task Order No. Q</u>

Enclosed are duplicate copies of three more articles from the literature that are of general interest in connection with the activity under this Task Order.

Sincerely,

[redacted] 25X1

ABW:dp

In Duplicate

Enclosures (3, in dupl)

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[redacted] 25X1

September 20, 1957

Dear Sir:

Task Order No. Q

Enclosed are duplicate copies of 12 articles from the literature and one advertisement. These items, and particularly the passages underlined in red, are of general interest in connection with the activity under this Task Order.

As the activity on this project progresses, we shall continue to pass on to you items of at least general interest with regard to the over-all objective.

Sincerely,

[redacted] 25X1

ABW:dp

Enclosures (13)

In Duplicate

C-1417

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First of a Series No. 1

Lateral Drain Hole Drilling

How important is this method of increasing well production? — A discussion of equipment development and the results

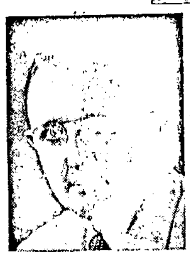
H. JOHN EASTMAN

The question, "How important is lateral drain hole drilling?" has been asked by oil men throughout the world. They also are interested in how successful it has been. To say that it is always the answer to increased production would be a fallacy. It has, however, in many instances been a method of getting oil from dry or nearly dry wells. It has also increased production. Lateral drain holes can be drilled out 30 to 100 ft from the main bore into the hitherto untapped oil sands, so that they may drain and channel the oil back into the bore.

Until recently, imperfections in the design of the necessary drilling tools, and the failure of anyone to assemble all the case histories of experiments with drain holes led to considerable skepticism in the oil industry about their value.

This first in a series of articles has for the first time assembled all the known data on the drilling of lateral drain holes.

The Author



H. John Eastman is founder and president of the Eastman Oil Well Survey Company, a specialized service company for directional drilling and oil well surveying in the oil industry. He has written many articles on directional drilling and oil well surveying and is considered an authority in the industry. Eastman's early days in the oil industry were spent as production superintendent for Magnolia Petroleum Company in Oklahoma. Later he was a salesman for Standard Oil of California. The company bearing his name was founded in 1930 in Long Beach, California. Today it is known throughout the industry as the pioneer in its field. The firm operates 26 offices in the United States, 5 in Canada, and 1 in Germany.

DEVELOPMENT of equipment and techniques for studying producing reservoirs show much more oil is left in the productive sand than is extracted by ordinary methods of recovery. Since many of the stripper fields were drilled when recovery methods were not as well perfected, new techniques are being tried experimentally to increase ultimate recovery. Undoubtedly many wasteful methods were used in primary recovery before production methods had advanced to the present state and development has not yet reached its peak. Probably we will look back to this time as one of inefficiency due mainly to lack of knowledge and tools to perfect better methods.

Lifting costs give impetus to the investigation of means for producing more of the oil contained in the reservoirs. As wells become older, the production rate declines and the unit cost of recovering each barrel becomes greater. Production equipment fails more frequently and, inflation has increased the cost of all remedial work without a proportional increase in the price of oil. Large quantities of water, lifted with the oil in older wells, are expensive to handle and contribute nothing to the operators income.

Much research and experimental work is being done at the present time to evolve new methods of secondary or even tertiary recovery. Gas repressuring and water flooding have been in successful use for years, recovering in many cases more oil than was drained from the reservoir originally. Accounts have appeared on experiments on burning a portion of the oil in place at the bottom of the well. By controlling this combustion process, the application of heat to the reservoir increases oil mobility by decreasing the viscosity of low gravity oils. Hydraulic fracturing has proved a great stimulant to further production in wells bottomed in certain types of reservoirs. Most of these new methods of recovering a greater percentage of the oil in place are confined in their applications. In most cases the payout of these systems is over the years and not in a few months of increased production. Few wells can be expected to attain the flush production they yielded originally.

EXCLUSIVE

One production aid to depleted wells has consisted of drilling short lateral holes within the oil sand out from the main bore. Lateral drain hole drilling is not to be confused with directional drilling which consists of deflecting the main bore of the well to bottom at a predetermined point generally at some distance from the surface location.

It has been deplored by many engineers that thousands of feet of hole is dug, cased, and maintained for years in order to produce from a relatively few feet of oil sand exposed at the bottom of the well. If this vital surface of contact with the pay formation could be increased, it was reasoned that the well should be more productive. Many attempts have been made to do this over the years.

Mining for petroleum, especially where gas depleted pay sands existed at shallow depths, has been practiced for centuries in some parts of the world. One of the first instances of oil mining in the United States occurred in 1865, when the New York Enterprise and Mining Company sunk a 165-ft shaft to an oil sand in Warren County, Pennsylvania.

Oil mining in Germany is being used as a successful secondary recovery method in several shallow fields. At Wietze, oil mines have yielded 5,000,000 bbl of oil in the last 32 years, more than the 480 wells drilled into the same sand produced in 80 years. The reservoir is made up of loose, dry oil sands, sandstones and limey sandstones from 210 to 240 ft thick. It is estimated that mining will yield 26.5 per cent of the oil content of the sand ultimately. Present production of the Wietze mine is about 400 bbl per day.

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Segments of Lee's angular drilling tool assembled and bent to maximum curvature. Lug on side engaged groove in deflector to preserve initial orientation.

At Pechelbronn the oil bearing sands and sandstones occur in lenses from 7 to 10 ft in thickness. About 6,250,000 bbl of oil have been recovered by mining processes in this field. Daily oil production of the Pechelbronn mine is 530 bbl of oil at present.

Mining is classified as direct or indirect. In the former system tunnels are driven into the reservoir itself to make the rock yield by free seepage. The indirect method of mining consists of driving tunnels in the beds overlying or underlying the reservoir itself. From there the reservoir is tapped by underground shafts or subsurface wells.

Oil mining ventures indicate that a greater exposure of productive sand in any well is desirable and that much oil otherwise unrecoverable is produced.

A review of old patents concerned with the idea of exposing more oil sand in a well is revealing. A United States patent was granted to J. L. Addison in 1891 on a "Groove Cutting Machine for Oil or Gas Wells." The object of this intervention was to "renew or increase the flow by opening fresh fissures, channels or cavities."

Bernard Granville of New York applied for patent coverage on a drilling apparatus in 1919 for drilling horizontal holes extending out from a main bore. Granville hoped to reach sources of oil and gas "within a radius of several hundred feet" by drilling laterals with his apparatus.

In 1929 and 1930 Granville received patent protection on two types of heavy duty flexible drive shafts which obviously were invented to drill lateral drain holes when used with the casing and elbow assembly.

Between 1922 and 1931 four other patents were granted on apparatus designed to drill lateral holes. All of these seem to be somewhat impractical in the mechanisms used for drilling. Probably they all failed because the equipment was not designed with sufficient strength to drill laterals successfully.

Prior to 1929 a number of experiments were made on the movement of oil through media by the Bureau of Mines. Models of different types of reservoirs were constructed and the oil was extracted from them by conventional methods. These studies were made at Bartlesville, Oklahoma, and Oil City, Pennsylvania, where they could be observed by reservoir engineers.

One of the observers of these tests was Robert E. Lee of Coleman, Texas, who left the experiments convinced that ultimate production could be increased by forming channels in the oil sand itself. He had seen the effect of explosives and reasoned that some practical mechanical device could be invented that would bore auxiliary channels out from the well bottom. Lee's original idea was to use an air actuated bit of the percussion type for cutting lateral holes. This apparatus was designed and operated experimentally and an application for a patent was filed in 1930. Trials proved, however, that a rotary bit would give much better results, so Lee redesigned and constructed improved equipment.

This rotary mechanism was constructed and used to drill lateral holes in a number of wells in Texas fields. The assembly consisted of four main parts — a deflector section for forcing the bit to drill in a certain desired direction, an air driven bit and reamer for drilling the lateral, a set of drilling segments directly above the bit which flexed in one direction only and locked at the limit of bend, and a similar set of non-locking segments run above the locking sections and connecting with the conventional drill stem.

This equipment was successfully used to drill the first truly lateral holes in 1929 at Texon, Texas, for the Big Lake Oil Company. Two 5¼-in lateral holes were drilled out 23 to 24 ft horizontally from the original well bottom in the St. Andrews lime at depth of about 3000 ft. Before the laterals were drilled the well was producing about one and one-half barrels of oil per day from the depleted lime reservoir. For the next 10 days after the drain holes were drilled, the well produced at the rate of 60 bbl of oil per day. Subsequent production figures are not available but the well was abandoned 4 years later.

Lee, wishing to verify that the laterals were actually drilling to horizontal or above, made the first survey of a drain hole in 1931. He used a set of acid bottles in short segmented barrels and, from these drift records, established that the bit was forced to drill horizontally on a very short radius. In fact, one hole 70 ft in length turned upward to form a "U".

Some time in 1939 Lee started to redesign his angular drilling tool to overcome the disadvantages proved by experience in drilling with an air motor. The subsurface air exhaust had proved impractical and no simple solution for surfacing the air had been found. The removal of cuttings was complicated by fluid, also the use of air and large compressors was costly and dangerous. The main new feature of the tool was that the bit was driven by rotating the drill pipe at the surface in the usual manner of conventional drilling. Drilling fluid served to lubricate and cool the bearings on the drive shaft and universal joints, as well as to remove the cuttings from the lateral hole. As the bit was free to move longitudinally in its bearing, it was forced ahead by the pressure of the circulating fluid also.

This improved angular drilling equipment was first tested on the Stone-Willis well in Brown County, Texas. This well was producing 60 bbl of salt water, having been drilled 10 years previously. It was used as a test only, since there was no possibility of getting further oil production. Three 25-ft lateral holes were drilled at a depth of 2600 ft. Water was employed as a circulating fluid with drilling done with 500 psi pump pressure. The 5¼-in. bit was run with a weight of 400 lb per in. of diameter or about one ton total weight. Production of salt water was increased from 60 bbl per day to 400 bbl per day after the lateral holes had been completed. The new type drilling equipment operated much better than when the air motor had been used. Some trouble was experienced with the

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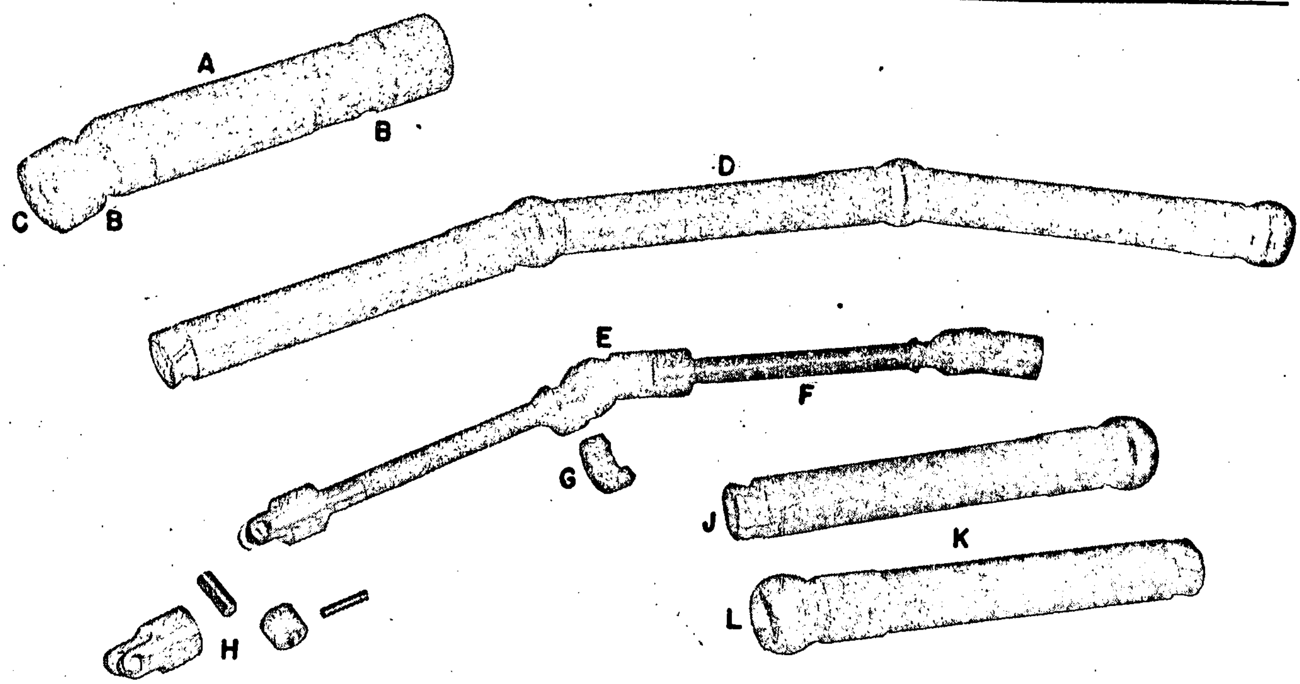

Parts of drilling section of Lee's second angular tool. Flexible segments are same as the first tool design. A. Bottom flexible section assembled. B. Flexible joints. C. Thread for drilling bits. D. Inner sections of flexible segments assembled to show amount of bend. E. Universal joint. F. Splined drive shaft. G. Split bearing for drive shaft. H. Universal joint assembly. J. Socket flattened to fit recess in ball at an angle to limit amount of bend. K. Hollow inner flexible segments. L. Ball with recess for socket. Two sides are flat and parallel.

sand in the circulating water cutting the bearings in which the segmented drive shaft ran. The tool worked very satisfactorily, however, and in this test increased the flow of salt water almost 7 times by drilling only 3 short laterals.

A depleted well in Coleman County, Texas, which made 20 bbl of oil per day was drilled with 2 laterals in the lime reservoir, one 3 ft and the other 16 ft in length. Water was used as a circulating medium for drilling the laterals. No increase in production occurred.

It was considered that the use of water prevented maximum benefits from the drilling of drain holes. The decision was made that in all future angular drilling, oil would be circulated to prevent contamination of the reservoirs. Oil also would serve as a lubricant for the moving parts of the drilling tool.

In 1935 and 1936 a number of wells were worked over with the angular drilling equipment in Shackelford County, Texas, using 30-deg gravity oil for a circulating medium. Most of the wells chosen for this type of workover were strippers yielding from 5 to 6 bbl of oil per day. Four old wells were reworked by drilling from 4 to 6 drain holes in the producing zone of each well. Short laterals that extended from 12 to 15 ft horizontally from the main bore were drilled in different directions like the spokes of a wheel. Production was increased from 5 bbl of oil to 20 bbl on the average.

Lee presented a novel method of repressuring and flowing wells by utilizing two sets of lateral drain holes spaced one above the other and the patent on this method was granted in 1931. He proposed to drill a number of laterals on two separate levels in the oil reservoir. A perforated liner would be run to a point opposite the lower set of drain holes with a packer set below the upper set of laterals. A repressuring medium would be pumped down the annulus between the casing and the liner and out into the upper horizontal holes in the sand to force the oil downward to the lower set of drain holes which would be produced. He also suggests that the repressuring gas to be superheated to reduce the viscosity of the oil and to dissolve viscous matter such as paraffin and asphaltum. None of the many angular holes he drilled were ever lined, however, nor was this novel method of repressuring used.

In 1941 Leo Ranney described a method for drilling horizontal holes within the oil sand for additional recovery from a depleted sandstone near McConnelsville, Ohio. A shaft was sunk to the depth of the oil sand and a drilling chamber of sufficient size to accommodate the drilling equipment and crews excavated. Six horizontal holes were drilled from this chamber out into the oil zone. The 3-in. diameter laterals were drilled in opposite pairs. A red pulling machine pulled the drill rods from one hole and ran them into a hole being drilled in the exact opposite direction. Thus drilling time was reduced since it was unnecessary to disconnect the rods. This drill pipe was run in and out at the rate of 100 ft per minute wherever it was necessary to change bits. With a crew of 2 men on the drilling machine, an average of 55 ft of hole was dug in a 7-hour shift. The holes were surveyed with acid bottles every 50 ft to be sure that they had not varied from the predetermined course. Over a mile and a half of laterals were dug in this way at an estimated drilling cost of 90 cents per foot. One hundred feet of light casing was grouted into the mouth of each horizontal hole after which each lateral was shot with nitroglycerin to break up the formation.

Ranney claimed that the shooting of these bores was more successful than shooting of vertical wells as the formation was broken parallel to the bedding plane of the sand. Since in one instance it was found that the 250 ft of earth over the hole had lifted 1½-in. it was concluded the explosive shock had shattered the beds vertically as well as horizontally. The first horizontal hole flowed by gravity, producing 5 bbl of oil per day in spite of a saturation of

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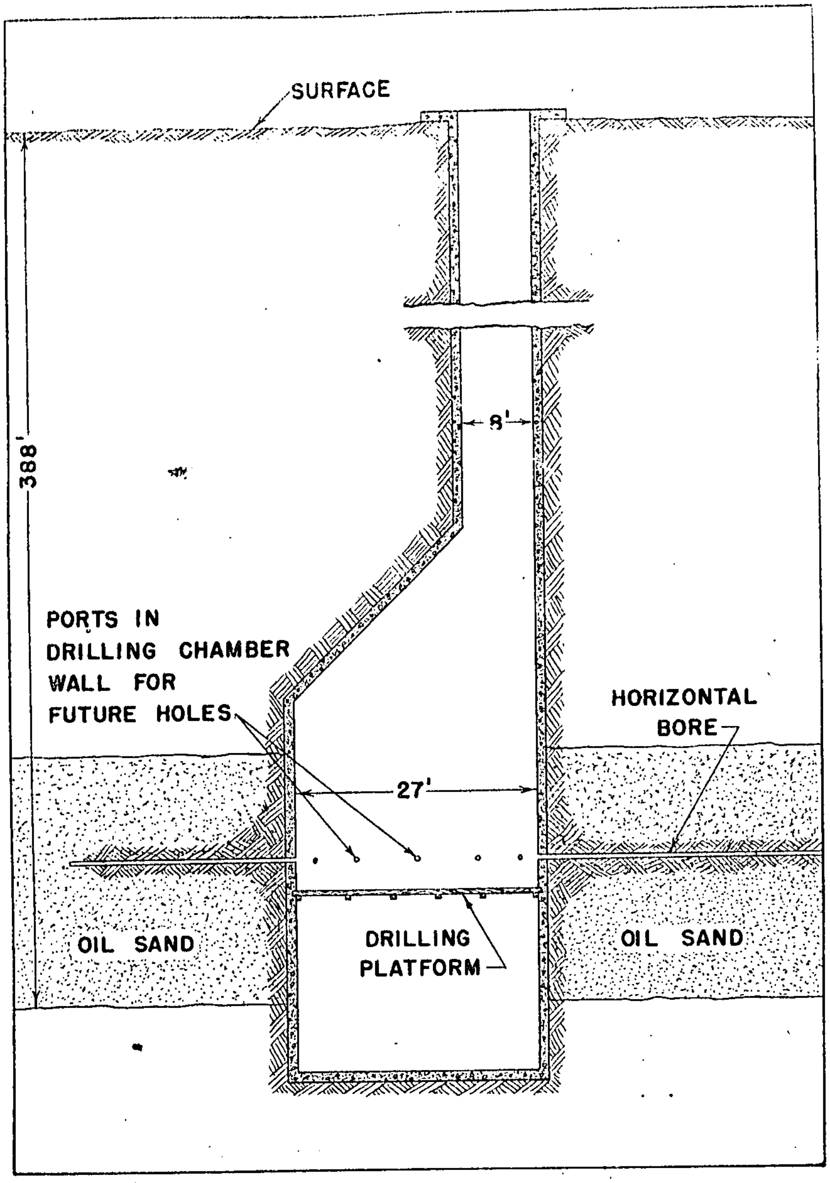

Sectional view of Ranney horizontal drilling chamber showing vertical shaft and horizontal holes radiating out into structure.

only 15 per cent. No serious difficulties were encountered in drilling any of these holes, in fact the drill rods never were stuck.

In May, 1942, a program of drilling horizontal holes from a shaft was begun in the Franklin Heavy field, Venango County, Pennsylvania. This reservoir had been produced by wells drilled between 1859 and 1861. Initial production of these wells ranged from 1 to 35 bbl per day. At the time of drilling the horizontal holes, the 20 wells on the 400-acre tract were producing 0.40 bbl of oil and 18 bbl of water per well per day.

A location was chosen near the center of the tract and a shaft was sunk to 388 ft. The concrete lined 8 ft diameter shaft was provided with a 27 ft lined working chamber at the bottom. From this chamber horizontal holes were drilled through ports in the walls. The first 100 ft of each hole drilled was 5-in. diameter and was lined with 3½ wrought iron casing with cement grouted in the annular space between the formation and the casing. Three-inch diameter hole was drilled thereafter. Two holes were drilled initially, one 2255 and the other 2334 ft. The drilling rate averaged 22 ft of hole per shift. Most of the distance was cored and an acid bottle survey run at 100 ft intervals and the holes kept at an upward inclination of about 1 in. in 10 ft.

Both drill holes were loaded with 80 per cent high velocity gelatin dynamite to within 400 ft of the shaft wall. In all 10,600 lb of explosive was loaded into the holes and detonated. The holes were cleaned out for their complete length by use of a perforated pipe and reverse circulation of water. Rock fragments were flushed into the tool and were removed. Part of one hole was redrilled with a fishtail bit to remove a bridged section.

Due to excessive costs of drilling the first 2 holes, the original plan for drilling 24 long horizontal holes radially from the shaft to drain oil from the whole 400-acre lease was abandoned. Ultimately, four 1000 ft laterals and four 600 ft horizontal holes were drilled. The first 2 long holes produced by gravity and 1 month after the drilling was completed, total production from the holes was 20 bbl of oil per day. This was considerably more oil than the 20 conventional wells yielded and their production was not affected. Later 15 points of vacuum was applied to the horizontal wells which increased production considerably. In September, 1944, the vacuum was increased to 21 points and it was reported that 126 times as much oil per acre day was extracted from the sand as the vertical wells had yielded in 1940. In March, 1945, the horizontal bores still were producing 20 bbl of oil per day and 80 bbl of water. In 1948 it was reported that the 2 longer holes had plugged and were no longer producing. Ten barrels of oil per day was the total yield of the shorter laterals.

While Ranney was drilling horizontal wells from shafts another inventor became interested in drilling laterals.

Zublin curved pipe with turbine bit.

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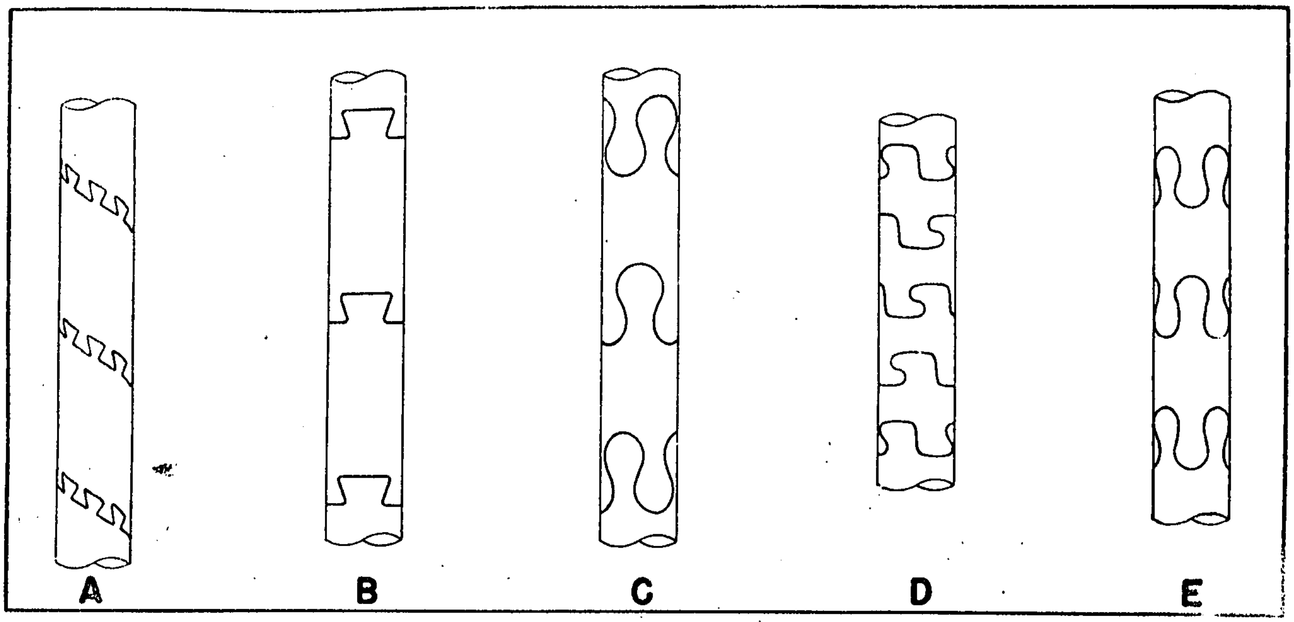

Different types of cuts to make drill pipe flexible. A. Spiral cut used on Zublin's flexible drill pipe. B. Keystone or dovetailed cut used on Eastman flexible drill pipe. Note that center of lobes is staggered 30 deg between each cut to prevent pounding of pipe when rotating. D. Experimental type cut for maximum flexibil... E. Four lobe type cut used on Oil Well Drain Hole Drilling C... pany's flexible drill pipe.

John Zublin, inventor of a novel type of rotary bit, turned his attention to the problem of digging laterals from the main bore of an ordinary well.

Zublin's first patent application was filed in December, 1941, on a tool to drill laterally from the main bore into the productive zone. It consisted essentially of three different pieces of heavy drilling equipment. Two types of flexible drill pipe and a fluid-operated turbine motor with a special bit were designed to dig the lateral holes. It was not planned to rotate the pipe. It was to act as a guide for forcing the bit to penetrate out of the main hole and was made flexible so it could follow the curved course of the bit. A number of sections of the best grade of drill pipe available were given the elasticity and resiliency of spring steel by special heat treatment. A continuous spiral slot was torch cut through the wall of the drill pipe over its entire length except for a 15 in. section at each tool joint end. This made the pipe flexible so that it could be run into a curved hole, but it would return to its normally straight form when not forcibly bent. Each section was lined with high pressure hose which was riveted at the ends of the flexible pipe to conduct fluid without leakage. One special curved type section was manufactured. It was similar to the flexible sections except that it first was bent to a definite radius of curvature and heat treated to retain its curved form. The turbine motor and bit assembly was as short as possible (20 in. length) and was attached to the bottom of the curved pipe for drilling.

This equipment was used in the following manner. As many lengths of straight flexible pipe as was needed to drill the length hole desired was made up on the conventional drill pipe or tubing to be used in laterally drilling the well. The single section of curved resilient pipe was made up on the bottom of the flexible pipe and the turbine bit was screwed onto the bottom of the curved pipe. This drilling assembly was lowered to the open hole and the tool was turned to face the bit in the direction in which it was desired to dig the drain-hole. Drilling mud of high viscosity was pumped down through the drill pipe into the turbine motor which rotated the bit.

As the curved pipe tended to resume the curvature to which it was bent and heat treated initially it pressed the bit against the side of the main bore with considerable force. As the bit rotated, it cut a side pocket in the vertical bore and gradually dug a lateral outward and downward from the original hole. As the bit dug the pipe was lowered to crowd the bit. The inherent resiliance of the curve pipe made the angle in the lateral increase due to side pressure on the bit. The flexible drill pipe and curved pipe were not rotated; they merely conducted the fluid to the turbine. The curved pipe forced the bit to bite into the wall of the original hole and the flexible sections followed the pipe into the curved lateral as drilling proceeded.

Zublin's equipment was the first which did not employ a whipstock to deflect the new hole away from the main bore. If it was desired to drill a straight section beyond the curved lateral hole, the assembly was withdrawn from the hole and the curved pipe removed. Drilling was resumed with the bit on the flexible pipe. Zublin's second patent covered a simple mechanism for forcing the bit to enter the mouth of a lateral already partially drilled.

Considerable difficulty was experienced in straightening the resilient curved pipe enough so that it could be run down through the casing and into the open hole. This objection was overcome by straightening the curved section in a clamping device before it was run into the hole. As it was held in this position a stiff cylindrical mandrel was inserted into the curved pipe which reduced its curvature. After the assembly was run to the desired depth in the well, an overshot lowered inside the pipe on a sandline retrieved the mandrel. The resilient pipe then assumed its curved shape, pressing the bit against the side of the hole to start the lateral.

Drilling was done with very light mud or clear water. About 300 to 400 gal of fluid per minute was delivered to the bit with a slush pump under 600 to 700 lb pressure. Weight carried on the bit was very low; never over 3000 lb. An efficient mud screen shaker was needed to remove all abrasive sand from the fluid to minimize wear on the turbine bit.

This equipment was tried experimentally on two wells in the Midway-Sunset field in California's San Joaquin Valley. Oil zones between 1100 and

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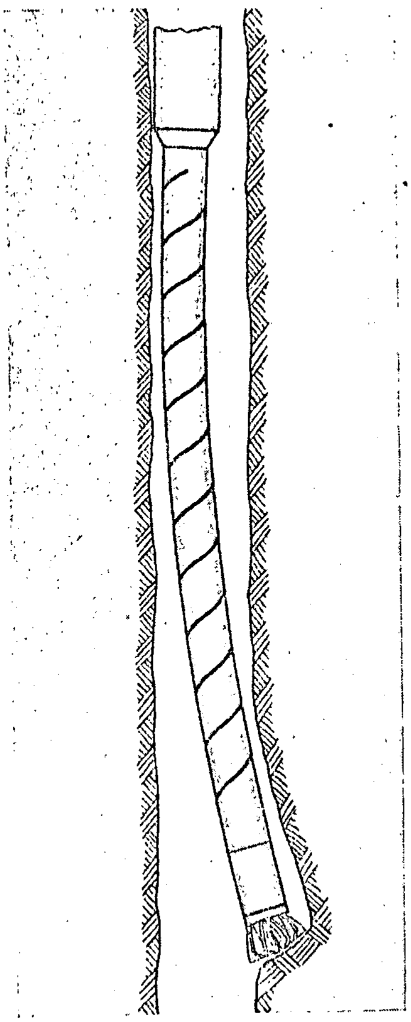


Turbine bit starting to dig lateral. Resiliency of the curved pipe forces bit to one side of hole.

1500 ft depth were drilled with drain holes after windows had been cut in the liners at the correct depths. Curved pipe bent to a 20 ft radius forced the turbine bit out through the windows. Three drain holes were drilled in one well in lengths from 52 to 72 ft.

Eight drain holes were drilled in one shallow well in the Midway district which originally was drilled and completed in a conventional manner in 1918. It produced until 1928 when it was shut down as the daily production had declined to 1 bbl of 12 to 14 deg gravity crude per day. Seventeen years later, in 1945, the well was sidetracked and 8 drain holes were drilled in the oil zone below the 12½-in. casing. Four hundred twenty-one feet of laterals were drilled each one averaging 53 ft in length. Light weight mud was circulated to operate the turbine bit and wash the cuttings from the hole. Pump pressures varied between 400 and 600 lb. The speed of drilling varied considerably but it averaged about 1 ft per minute. After the drain holes were completed the fluid level stood 300 ft off bottom. Daily production increased from 3 bbl immediately after drilling to 25 bbl per day, a month and a half after the workover. Production of sand dropped from 35 per cent to 8 per cent during this same period. It is reported that the well produced 20 bbl of oil per day for a number of years.

The same tools drilled a total of 458 ft of laterals at depths from 1650 to 1680 ft in a well in the Round Mountain field in Kern County, California, in July 1946. The well bottomed in an 80 ft thickness of oil sand at a depth of 1720 ft. All of the 9 laterals were drilled below the 8⅝-in. casing in open hole and were oriented with 2 holes in each quadrant. Three of the holes were drilled in a S 19 deg E direction as one was very short. The longer holes averaged 56 ft each. This work was completed during a period of 4 working days. The penetration rate was about 30 ft per hour using crude oil as a power fluid for driving the bit.

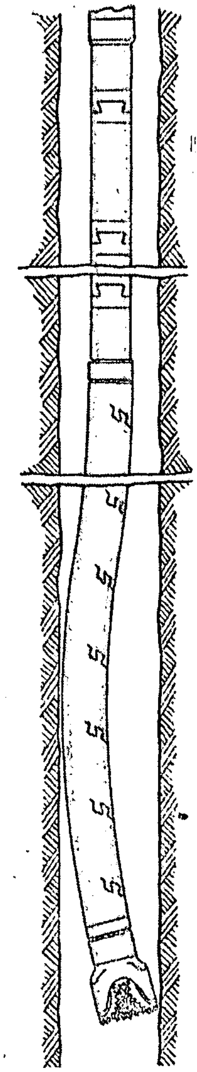
In 1947 the helical slot cut in the pipe was redesigned to give it more strength since laterals were being drilled in deeper wells. Experience had shown that the helically slotted flexible pipe with a smooth edged slot deformed badly under excess weight. If enough weight was applied, the upper section expanded and telescoped over the next lower spiral section ruining the pipe and causing the hose inside to burst. The new slot still followed a spiral path around the pipe but was cut in the shape of interlocking dovetailed teeth. Each tooth had straight sides diverging from its root and it terminated in a straight edge parallel to the helical path of the slot. Thus, when the pipe was compressed, the inter-meshing teeth prevented it from failing.

Sometime in 1948 use of the turbine bit was abandoned and the tools were redesigned so that ordinary rock bits could be used for drilling. The fluid propelled motor and bit were eliminated entirely, and the flexible and curved pipes were made to rotate a tricone bit rather than to function as a guide.

Recently Zublin has received coverage on the use of his drill guide and flexible drill pipe off a deflector to assist in starting the lateral hole in hard formations.

Eastman lateral drilling equipment incorporates some ideas derived from experience gained in directional drilling. A universal knuckle joint is used to force the drilling equipment to increase drift as its digs.

Two sizes of lateral drilling equipment are available. The 4¾-in. lateral tools are designed to use a 4¾-in. diamond or rock bit cutting laterals from a 6 to 6¼-in. main bore. The 3¾-in. tools are made to use a 3¾-in. bit to dig laterals from smaller main bores. Only the 4¾-in. tools will be described as the smaller tools are practically identical except for size.



Modern Zublin lateral drilling equipment. Flexible drive pipe above with drill guide below. Tricone bit is rotated by inner drive pipe, (not shown). Drill guide itself does not rotate normally. By its resiliency it forces the bit to drill laterally upward.

The lateral drilling tools consist of two separate assemblies; a whipstock and protective casing assembly and a drilling tool assembly.

The protective casing is 5½-in. OD 17 lb casing in lengths with internal and external flush tool joints. The amount of protective casing may be varied according to the situation in the individual well and the length lateral it is proposed to drill. The amount of casing used always is longer than the lateral to be drilled so that the flexible

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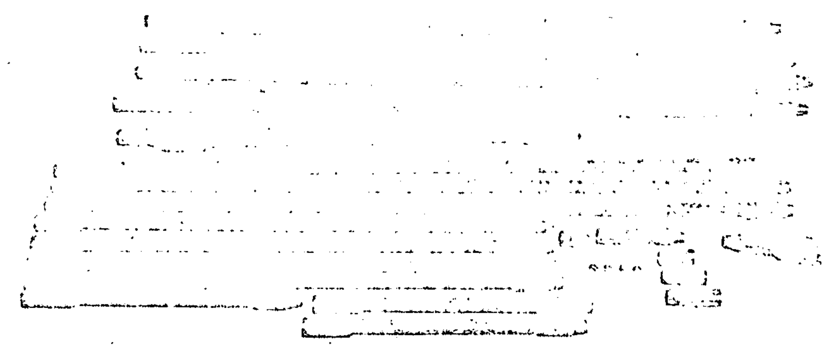

Eastman lateral drilling tools — top are 4 flexible collars run in above the whipstock which allows the bit to deviate rapidly. Below is special whipstock which forces bit to drill laterally. Lower left are various lengths of 3½ in. drill pipe used as tail pipe to set whipstock at any desired depth off bottom. Lower right are tricone drilling bit, knuckle joint, and various subs. The anchor bit used on bottom to prevent the whipstock assembly from turning also is shown.

drill collars are kept from keyseating in the main hole. Often enough casing is used so that it extends up into the casing string set in the well thus safeguarding the well in event of a fishing job. A shear pin casing nipple is screwed into the top of the casing assembly. The nipple is equipped with a threaded hole and pad to accept a steel shear pin which screws through the casing and into a shear pin sub in the drilling tool assembly.

Made upon the bottom of the protective casing is the whipstock section 5½-in. OD and about 10 ft long. The tapered section of the whipstock face is 3 ft 8 in. long and is curved in radius to cause the drilling bit to dig upward and increase angle. The whipstock has a triple purpose. It forces the bit to increase angle at a uniform rate and insures that the point of deviation from the main bore is at the exact depth desired as well as insuring that the bit starts in the right direction. No time is wasted in forming a shoulder to start the hole, since the bit is forced to dig laterally as soon as it is rotated and weight is applied. Use of a whipstock insures that the lateral is started in the correct direction.

The bottom of the whipstock section is equipped with a tool joint pin to accommodate the box in a releasing sub run below it. The releasing sub is interposed between the whipstock section and the tail pipe as a safety feature. If the tools should become stuck in the hole, the sub releases on a 15,000 lb straight pull. Thus the whipstock and protective casing can be withdrawn from the hole and the tailpipe fished if it becomes stuck. The tail pipe consists of lengths of 3½-in. drill pipe with external flush tool joints. Tail pipe sections vary from 5 to 30 ft in length so the whipstock can be set at any distance off bottom desired. An anchor bit is screwed on the bottom of the tail pipe. Slots cut in the face of this bit cut into the formation at the bottom of the well and prevent the assembly from turning after it is once set. Circulation holes provided in the bit make it possible to circulate to bottom if the tailpipe must be fished from the well. The whipstock and protective casing assembly serves to start the drilling tools in the correct direction at a uniform rate of increase in angle and at the depth at which the lateral is planned. It also encases the flexible drilling tools so they are protected in the main bore as the bit digs the lateral.

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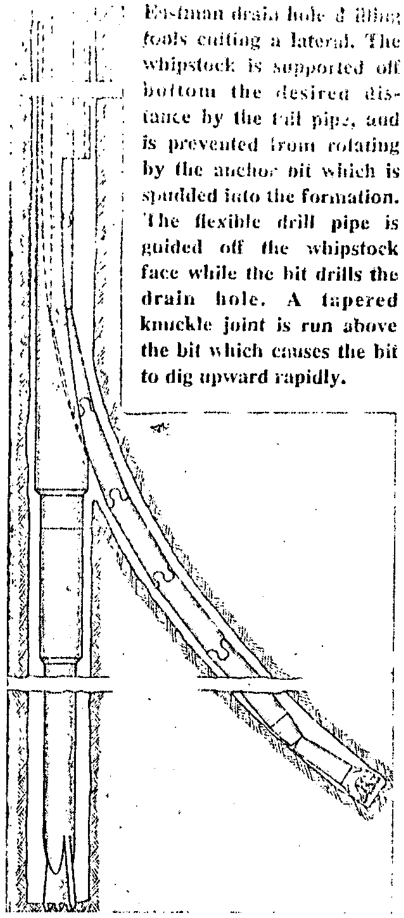


Eastman drain hole drilling tools cutting a lateral. The whipstock is supported off bottom the desired distance by the tail pipe, and is prevented from rotating by the anchor bit which is spudded into the formation. The flexible drill pipe is guided off the whipstock face while the bit drills the drain hole. A tapered knuckle joint is run above the bit which causes the bit to dig upward rapidly.

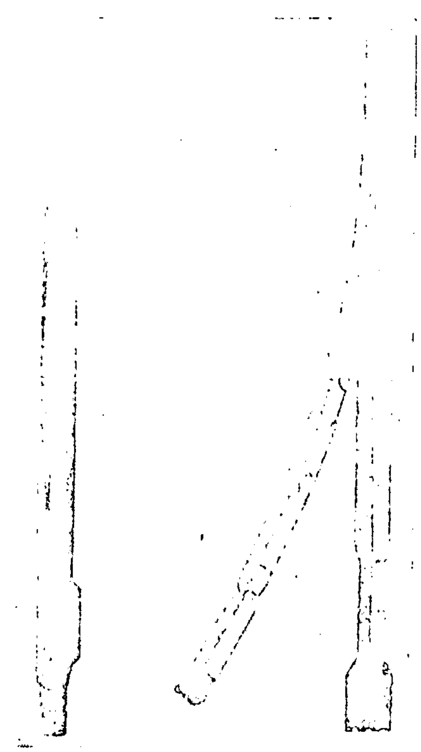
The drilling tool assembly consists of a shear pin spiral sub, a number of flexible drill collars, a universal knuckle joint, a short spiral reamer, and a rock or diamond bit. The flexible drill collars are approximately 16 ft length sections, 4¼-in. OD with a 2-in. internal bore. These flexible sections are made from standard drill collars with 2⅞-in. API internal flush tool joints. A special type of 3 lobe clover leaf cut is made through the collars on 9⅛-in. centers. Cuts are made with a torch and template which guides the torch. The width of the cut is regulated carefully to limit the flexibility of the pipe. A wide cut makes the pipe very flexible; a narrow cut reduces the radius on which the pipe may bend. In cutting the clover leaf or three lobe design the flame of the torch is pointed at the center of the bore of the drill collar at all times. Thus the outside of the lobe is larger than the inside. This feature prevents inter-engaging sections from separating.

The lobe pattern is not spiraled around the pipe but is formed perpendicular to the long axis of the drill collar. As each set of lobes are cut the template is rotated 30 deg around the pipe so lobes are not cut from the same starting points. Being staggered at 30 deg intervals, every fourth joint cut is in alignment. Thus the pounding of the flexible joints as they are rotated in drilling is eliminated. The drill collars are heat treated to relieve stress after the torch cuts are made. Each flexible collar is lined with a rubber tube to carry fluid to the bit. The circulating hose is 1000 lb test Neoprene rubber with couplings at each end. Provision is made for the hose to slide as the drill collars are flexed. Sliding seals made tight with "0" rings prevent circulation leaks. These connections have been designed to facilitate the changing of hose at the rig in a minimum of time.

All of the flexible drill collars are identical in construction. The number of flexible drill collars used in the drilling assembly varies with the length lateral to be drilled. At least 10 ft more flexible pipe should be used than lateral length. The shear pin spiral sub is made up between the flexible collars and the ordinary drill pipe or tubing used for drilling. The sub has a hole drilled and tapped in its side to receive the shear pin which is screwed through the shear pin casing nipple into it. A set of spiral blades cut off the broken end of the shear pin as the sub drills by. A universal type knuckle joint is run between the bottom of the flexible drill collars and the digging bit. The knuckle joint transmits torque from the flexible collars to the bit through drive pins in a ball and socket joint. A circulation hole is provided down the center of the universal joint to carry mud to the bit. The diameter of the knuckle joint reduces toward center from both ends. The relation of the greater and lesser diameters and the length from the face of the bit to the pivot point of the knuckle joint is quite critical and varies the limit of the ability of the bit to dig upward.

When weight is applied to the assembly the bit tends to cut out the upper side of the hole making the drift angle increase rapidly. Most drilling setups are built to dig upward at the rate of 2 deg increase per foot which makes the lateral turn upward on a 30 ft radius. For most soft and medium formations a tricone rock bit is used. Whenever the formation is suitable, laterals are cut with a diamond bit. In some cases a very short spiral reamer is run between the bit and the knuckle joint which acts as a fulcrum as weight is applied to the drilling assembly forcing the bit face to incline upward. This action causes the angle to increase and the spiral ribs ream the hole to gage reducing binding of the flexible collars as the lateral deepens. The length and diameter of the reamer is critical and must bear a relationship to the diameter of the knuckle joint and bit.

The lateral drilling tools are used as follows: The whipstock section and releasing sub are made up and the required amount of tail pipe (varying with the bottom depth and the depth at which a drain hole is to be drilled) is screwed onto the sub. The anchor bit is made up on the bottom of the tail pipe. Sufficient length of protective casing to house the required number of flexible drill collars is made up on top of the whipstock assembly with the shear pin casing nipple on the upper end of the casing. Then the shear pin sub is made up on the drill pipe or tubing to be used for drilling the lateral and flexible drill collars screwed onto the sub. The universal knuckle joint and bit are screwed onto the bottom of the flexible collars. The drilling assembly is lowered down through the protective casing assembly until the hole in the shear pin sub and the shear pin casing nipple coincide. A shear pin is screwed through the nipple into the sub. This connects the two assemblies together.



Eastman drilling tools as they appear when bit is in position to drill off whipstock and initiate lateral hole are shown at left. Bit and knuckle joint are guided by whipstock face which causes bit to dig in the chosen direction. Right photo shows position of lateral drilling tools after drain hole is well started. Knuckle joint above bit is fully flexed to force bit to dig upward.

If the tools are to be oriented from the surface, the whipstock is faced in a known direction and orientation is carried on as the assembly is lowered into the well. When bottom is ap-

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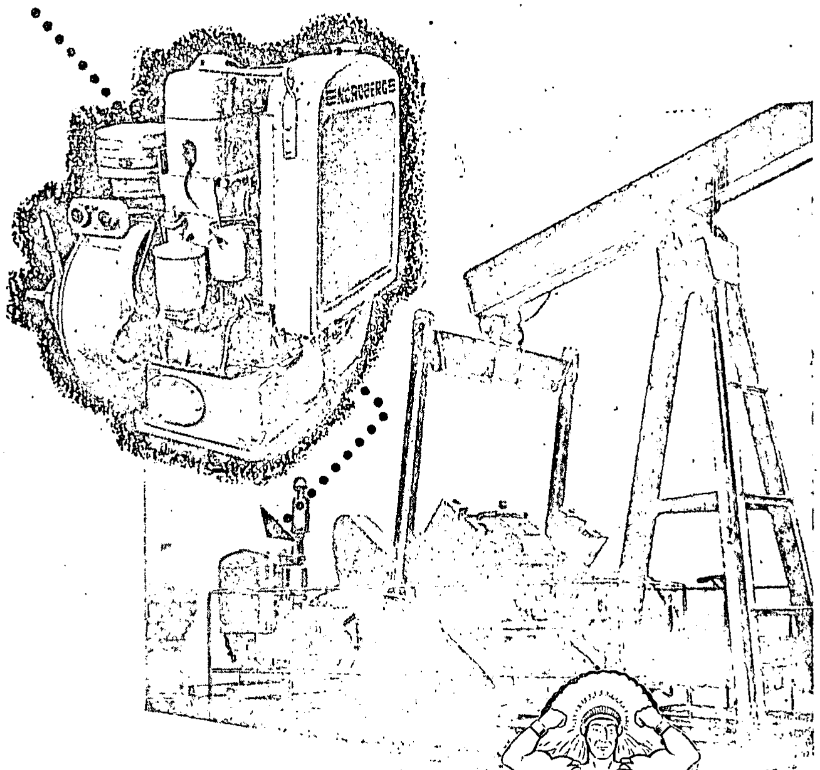
proached the tool is faced in the desired direction and spudded on bottom to seat the anchor bit in the formation at the bottom of the well. Further application of weight shears the pin so that the drilling assembly is free to rotate. The drilling tools are lowered so that the bit lies on the face of the whipstock and circulation is established. The drilling string is rotated at about 60 rpm and lowered to start digging. The whipstock forces the bit to incline upward and guides it in initial direction. After the bit drills off the whipstock, more weight is applied to crowd the knuckle joint to the bottom of the hole and force the bit to drill upward. The bit is lifted off bottom occasionally as drilling proceeds to circulate the hole clean.

As soon as the required length of lateral has been dug the tools are hoisted out of the drain hole. The whipstock and protective casing assembly may be left in the well temporarily or brought out with the drilling-assembly. When digging in hard formation where more than one bit is dulled in drilling lateral, or if a liner is to be run, or the hole is to be surveyed, it is desirable to leave the whipstock in place in the well until all of the operations are completed. In this case the whipstock and protective casing assembly are finally retrieved with a casing spear run on the drill pipe. In softer formation where one bit will drill a drain hole and no liner is to be set or survey made, a lifting sub is run below the shear pin sub which brings the whipstock and protective casing assembly out of the well when the drilling assembly is withdrawn.

The use of a whipstock has decided advantages. Whenever it is necessary to withdraw the drilling assembly to change bits or check the equipment the whipstock left in place in the hole guides the tools back into the lateral. A flexible liner run into the drain hole after completion likewise is guided into the lateral without probing. If a survey is made the barrel enters the hole easily. In no case has any trouble been encountered in retrieving the casing assembly with a spear after any of these operations. No tail pipe has been stuck in the well; use of a releasing sub is only a safety feature in case the tail pipe should stick.

Crude oil or oil-emulsion mud is recommended as a circulating fluid in lateral drilling but two holes were successfully drilled with gas. Laterals have been drilled successfully in both hard and soft formations with these tools.

The Oil Well Drain Hole Drilling Company uses drilling tools somewhat similar to those described above. One of the main differences in their equipment is that the flexible drill pipe is made with a four lobe cut. ★ ★ ★



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P 422.

Second of a Series

No. 2

Lateral Drain Hole Drilling

Both surveying and lining at laterals are deemed important steps in successful application of the techniques

H. JOHN EASTMAN

IN the early part of 1951 a demand arose for surveys of lateral drain holes with both drift and direction desired. Unit which recorded angle and direction from vertical to horizontal already had been developed and it was found that this older type multiple shot instrument could be reduced in length and powered with short flashlight cells. A 90 deg angle unit was constructed so it could be shortened about 2 in. An extremely short barrel was manufactured with a bronze guide welded onto the bottom bull plug to assist in entering the mouth of the drain hole.

A flexible joint at the top of the barrel was spring-operated to stab the barrel in the lateral when no whipstock was used in drilling. Some of the first barrels made were too long to successfully negotiate the short bend where the drain hole left the main bore. Finally a barrel less than four feet long was developed and has been successfully used.

In many instances the barrel was made up on the resilient curved pipe directly so the instrument would enter the lateral. Whenever drain hole tools employing a whipstock were used for drilling the laterals, an articulated duraluminum section was interposed between the barrel and flexible drill pipe. Thus the instrument compass was removed from the magnetic influence of the flexible drill pipe and accurate magnetic readings were obtained. Many successful surveys have been made with this equipment. Recently an angle unit has been developed which will give directional readings from 0 to 140 deg drift (50 deg above horizontal).

Usually readings are taken at one-foot or five-foot intervals as the instrument is withdrawn from the lateral. A timing mechanism in the instrument synchronized with a chronometer at the surface indicates the readings to apply to each depth at which a record is taken.

Surveys have been made on many laterals, especially those drilled in California since 1951. They have assisted operators in the evaluation of drain hole drilling and its application to the producers specific needs. As a result service companies have been guided to the redesign of their tools to make them drill laterals more nearly as desired by the operator.

A study of these surveys gives a remarkable accurate picture of the mechanical functioning of drain hole drilling tools and has made available valuable data that has led to their improvement. As further advances are made in this type of high-angled drilling and as holes penetrate further from the main bore, surveys will become more essential.

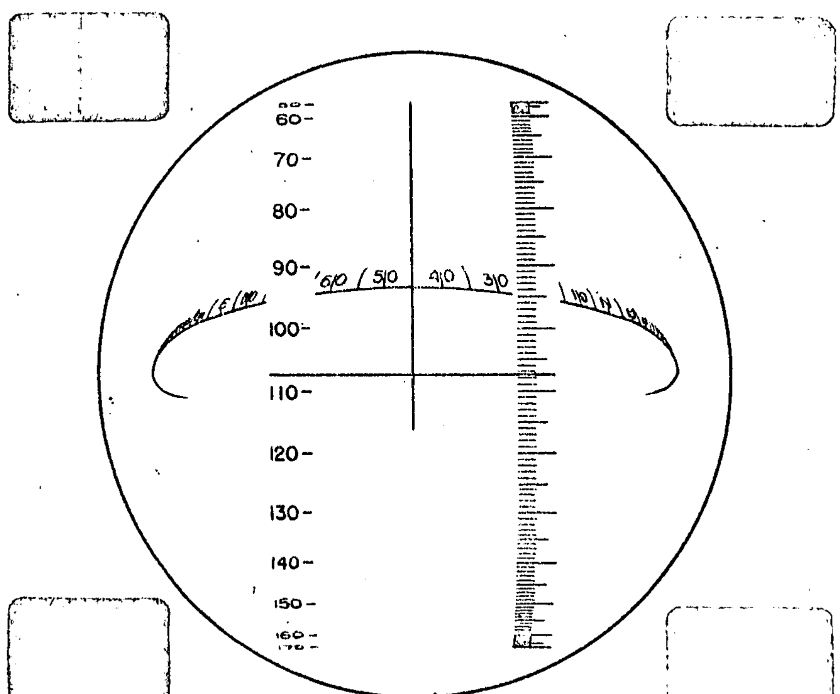
In many cases the knowledge of the course of the laterals will be important to the operator in whose well they are drilled. Drain holes dug in wells near lease lines must be surveyed to assure that they do not trespass upon an adjoining lease. Knowledge of the course of laterals near faults is needed and in steeply dipping sands, too great a depth penetration is liable to make the drain hole penetrate into water sands. Accurate directional surveys will assure that this has not occurred.

Drainhole Liners

Although Lee suggested the use of liners or other means of keeping drain holes open after drilling, he did not develop a technique for casing the laterals.

Although holes drilled with his equipment were left open and it was concluded that they stayed open, it is probable that they soon were filled and prevented the flow of oil from the ends of the laterals.

Most of the drain holes drilled in areas outside of California have not



Section of film from lateral drain hole survey instrument. The picture shows the lateral drain to be N 45 deg E at a drift of 107 deg 30 ft from vertical 9 or 17 deg 30 ft above horizontal. Readings are taken at desired intervals to show complete course of lateral.

EXCLUSIVE

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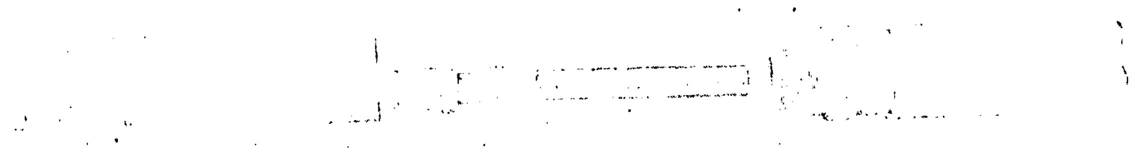


Bottom end of Eastman liner showing circulating shoe at right. Hose, sliding connection (center) are attached to pipe on which liner is lowered into lateral. Hose, connection, and shoe give circulation to bottom to assist in setting liner.

been lined; in fact, some treated with acid and hydraulically-fractured have not been cleaned out after treatment.

Recently the demand arose for a means to protect the laterals and assure that they carried oil to the main bore. As far as is known no positive means has been used to gravel-pack a drain hole completely from the extremity to the main bore to date. Whenever the main bore was flow-packed every attempt was made to flow gravel into the lateral but obviously the distant ends were not completely filled. The only practical method for doing this would have been to make a flexible tool to run the curved hole and flow-pack the lateral as the tool was withdrawn.

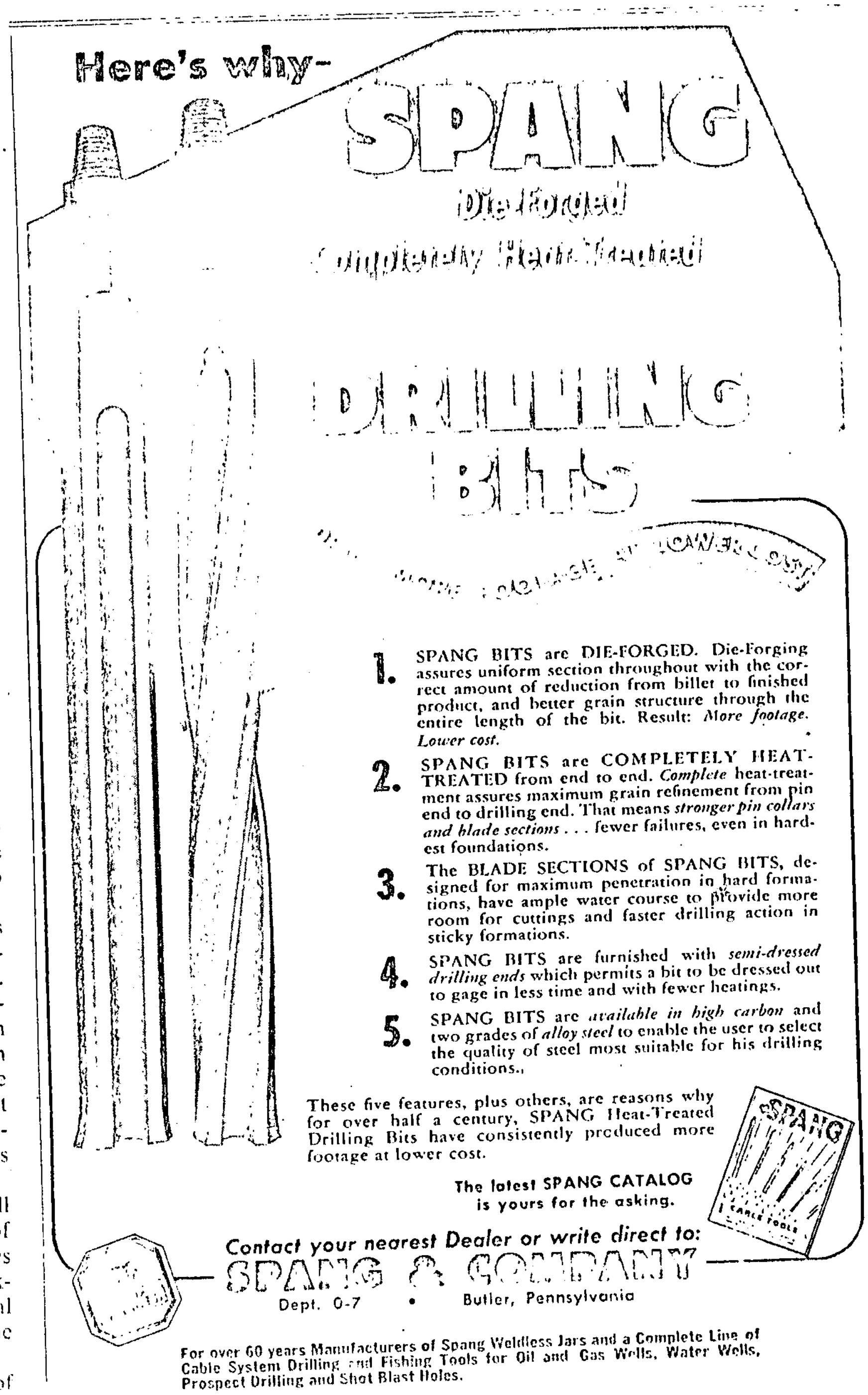
Today there are a number of types of liners that are run into drain holes. Sections of slotted liner are cut with lobes at short intervals to make them flexible. The outer section of some of these liners are prepacked with gravel. When running, a circulating shoe is attached to the bottom of the liner by means of a removable hose. Thus the drain hole is cleaned out as the liner is lowered into it. The liner is left in the lateral by a releasing sub. The circulation hose is attached to the flexible pipe and is withdrawn with it.

One type of liner is gravel-packed between the slotted pipe and a central oil-soluble hose. The hose is used to hold the gravel in place and to give circulation to bottom as the liner is being set. The hose is disintegrated by the oil in a few weeks, permitting oil to flow through the liner.

A liner of simple construction is being used effectively in the Wilmington and Torrance, California fields. Lengths of 2-in. slotted liner are prepacked with ¼-inch gravel to 4-inch OD, the gravel held in place with open steel mesh. Sections of this liner are joined to form a continuous pipe at least 5 ft shorter than the drain hole. A funnel shaped adapter of drillable metal is made up on the top of the liner.

The liner is lowered into the well and the adapter seats in the mouth of the drain hole. After all drain holes have been lined in this manner and excess liner milled off, a conventional slotted or prepacked liner is set in the main bore.

The adapter prevents the mouth of the drain hole from caving and maintains the effectiveness of the drain holes. The liner is easily run into the lateral due to its flexibility. When a whipstock is not used to drill the drain holes the end of the liner must be bent or a simple fluid-operated knuckle joint placed on the end to facilitate entry. * *



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/VO.9

New Method: Horizontal Earth Boring

Fig. 1. Pipe and bit after holing through in New York Library job in which Con Ed used horizontal earth boring equipment to cut through about 57 feet of rock and building foundation from a starting point about 10 feet below street surface, terminating inside the Library's basement wall. Part of area bored through was stonework of an old water reservoir wall on whose site Library now stands.

. . . Some 10,000 feet of pipe and duct are being installed annually by Con Ed with the specially designed mobile, self-contained equipment described here. It will handle up to 36-inch pipe, in many cases permitting installation without disturbing over-ground activity. Pipe bores as long as 90 feet have been made in a few hours. Equipment suitable for rock boring. . .

APPROXIMATELY 10 thousand feet of steel pipe and concrete duct are being installed yearly by the horizontal earth boring method on the distribution system of Consolidated Edison Co. of New York.

The Inspection and Methods Bureau of Con Ed's Outside Plant Construction Department has completed the design and construction of a new series of mobile, self-contained machines in a further effort to increase the economy and productivity of this method.

In horizontal earth boring a steel pipe of any size from 2 to 36 inches in diameter is propelled into the earth by rotation and jacking. The bit on the end of the pipe is capable of cutting its way through solid rock formations as well as all kinds of soil. The same type of bit is used in oil well drilling. See Fig. 1.

A commercially available material known as "Aquajel" is mixed with water to form a slurry which is pumped to the head of the pipe and through the bit as it moves into the earth. The slurry lubricates and cools the bit, mixes with the soil or rock chips and acts as a vehicle to carry the cuttings back to the boring pit. There, the slurry is sucked up and pumped to a vibrating shaker screen where the spoil is separated from the "Aquajel" which is then recirculated.

The trailer-mounted machine (Fig. 2) consists of a 26 hp. gasoline engine, coupled to a 30 gpm, 1200 p.s.i. hydraulic pump which is connected to a 15 hp., 1200 rpm hydraulic motor

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with a pair of high pressure hoses. The hydraulic motor is a part of the gear reduction assembly mounted on the scaffold portion of the trailer. This unit furnishes the rotation power to the pipe at a speed up to 40 rpm maximum and a torque of 23,000 in-lbs. Forward propulsion is obtained manually through roller chain and ratcheted come-along assembly.

This machine was designed primarily for mid-block and street intersection boring. An 8 foot by 20 inch trench is dug, usually on the sidewalk. The trailer is rolled over the excavation and the scaffold containing the boring unit is lowered into it, aligned and chocked. The machine is then ready to bore. Pipe bores from 30 to 90 feet long have been made with this arrangement in just a few hours. Three such machines are now in use in the Con Ed system.

The second machine (Fig. 3) of the new series was built on the chassis of what was once a U. S. Army searchlight trailer, as may be partially recognizable from the illustrations.

Ready to roll to a job location, this unit is compact and self contained. It is 14 feet long, 7 feet 10 inches wide and 8 feet 6 inches high. In use, the unit covers 70 per cent of the excavated area over which it sits and leaves only a small area that needs protection. It literally lifts itself by its own boostraps and is capable of boring pipe sizes from 2 to 6 inches in diameter for a distance of 150 feet. Like the "Two Inch Portable" it requires no connection or assembly in the field and has proved to be a real time and money saver in boring operations.

A rear view of the machine (Fig. 4) shows the track rail off the trailer hooks and being lowered by the electric-driven elevator. In the upper right is a gasoline engine used to drive an oil pump which is connected to a hydraulic motor that is part of the boring unit mounted on the rails. At the upper right rear interior part of the trailer is a 2 gpm, 7500 p.s.i. hydraulic pump which furnishes the propulsion power for two 20-ton cylinder jacks which engage the notched rail and push the boring unit forward. To the left, back of the valve, is a 500-gallon slurry tank that runs the full length of the trailer body. All operational controls are mounted at the rear.

The vibrating shaker (Fig. 5) is

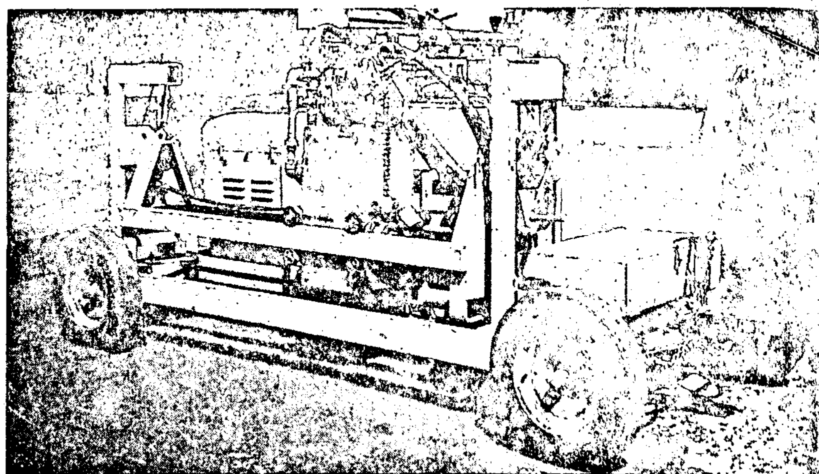

Fig. 2. The trailer-mounted machine shown here furnishes rotation power to the pipe at a speed up to 40 rpm maximum and a torque of 23,000 inch-pounds.

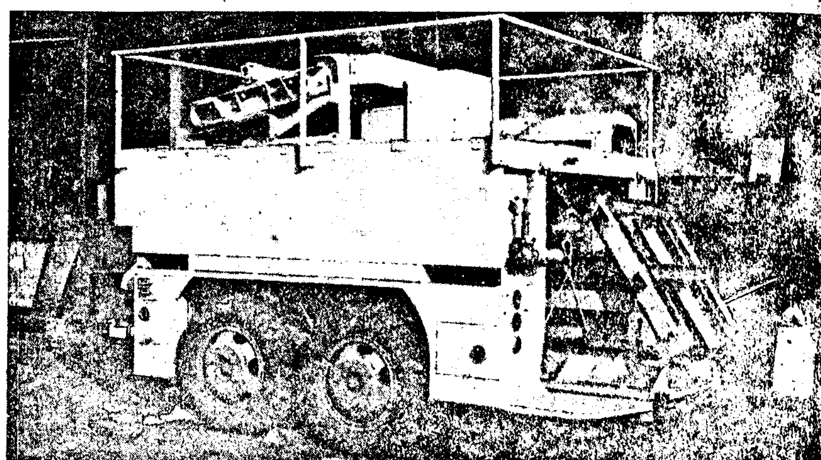

Fig. 3. Side view of one of types of horizontal earth boring machines used by Con Ed. This compact, self-contained unit using an Army searchlight trailer chassis.

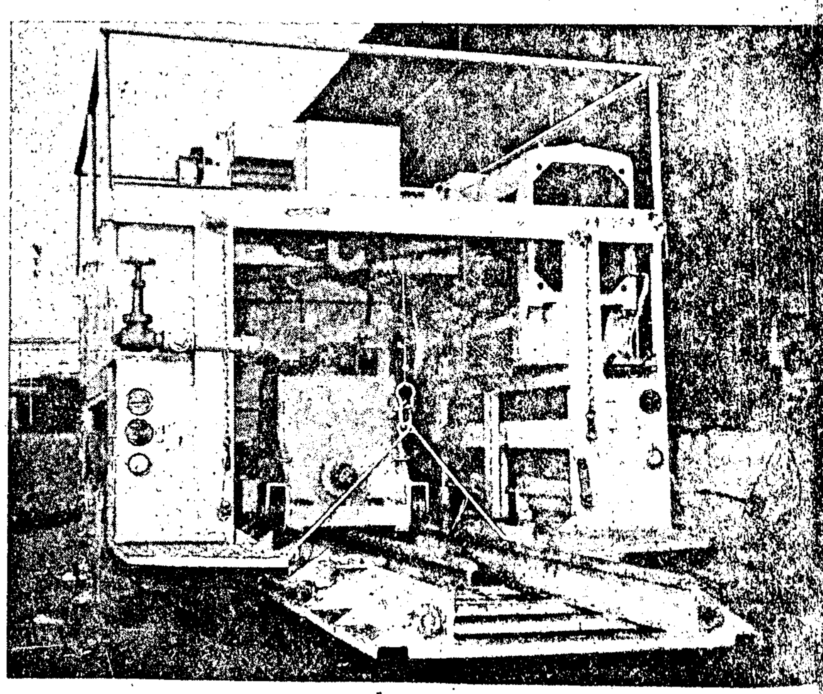

Fig. 4. Rear view of searchlight trailer-mounted horizontal earth boring unit, shows track rail trailer hooks, ready to be lowered, as it would be when in use, by unit's electric driven elevator.

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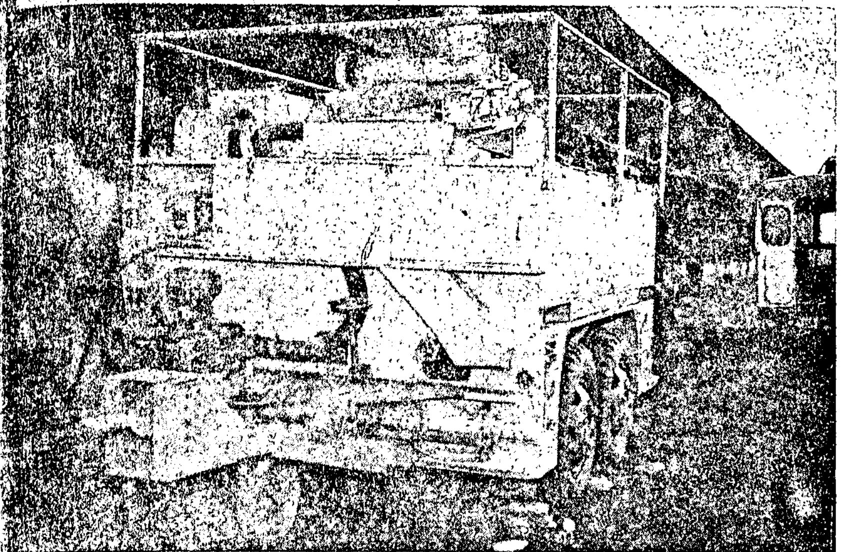

Fig. 5. Front view of the searchlight trailer-mounted horizontal earth boring unit.

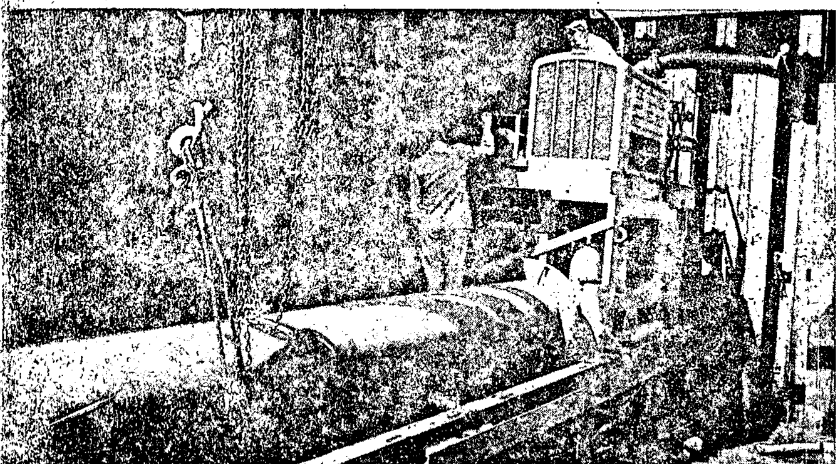

Fig. 6. This horizontal earth boring machine was used by Con Ed recently to install five 24-inch pipes under mainline tracks of New York Centrall Railroad. The use of horizontal earth boring equipment made it possible to accomplish job without interrupting train service.

Fig. 7. Getting set to start boring with one of the horizontal earth boring machines. As pipe to which bit is attached is rotated and jacked through rock and soil, bit cuts through. As bit and pipe penetrate into ground added lengths of pipes are welded on until bit emerges at far end of bore. Bit is cut off and pipe is in place.

mounted on the top deck. The suction pump is at the lower left, mounted on the tow bar apron. At the lower right side, in the cutaway portion of the apron, a barrel is placed on the ground to collect the spoil that has been separated from the slurry and dropped through the duct shown mounted on the front wall. Circuit breaker switches are visible in the partly open cabinet on the left. These actuate the electric motors on the high pressure oil pump, slurry pump, shaker screen and elevator.

Since this work is performed on public streets and highways, the new equipment has been designed for a quick set-up, a minimum of field assembly operations and a minimum need for work area protection devices. It is obvious that the less time spent at a location and the less space occupied in doing the job, the more we will contribute to better public relations and greater economy.

The largest machine of the new series is a power packed giant (Fig. 6) weighing 14 tons. It can bore pipes from 16 to 36 inches in diameter, for distances of 200 feet or more.

The boring machine is 12 feet high, 11 feet long and 48 inches wide. The front drive plate that engages the pipe is 38 inches in diameter and contains 3 drive bars spaced 120 degrees apart that can be varied radially to fit any size pipe from 16 to 36 inches in diameter. The track and reaction rails consist of two 18-foot sections. This unit can be disassembled for ready transportation. The smallest excavation that the machine can operate in is 19 feet long, 5 feet wide and the depth is determined by the depth at which the pipe may be required.

This machine, due to its size and weight, is not totally self-contained, like the ones previously described. A trailer containing the "Aquajel" tanks, slurry processing pumps and shakers is a separate adjunct of equipment.

On its maiden run this giant machine (Fig. 7) was instrumental in saving Con Ed a considerable amount of money over the standard methods of open trenching or tunneling. In this particular job standard construction methods would have caused a slowdown of main line New York Central train traffic. This was avoided by the use of the boring method. The machine completed its four sleeve bores successfully on schedule. Approximately 38 feet of rock had to be cut in each sleeve run. ■

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No. 4

Canadian Mining Journal
November, 1955

Robbins Tunnel Boring Machine

The Robbins Tunnel Boring Machine has driven a circular 25-foot, 9-inch tunnel through shale at a rate of 12 feet an hour without benefit of explosives. Low costs and increased safety are other benefits at Oahe Dam in South Dakota where conventional methods were discarded in favour of this revolutionary machine.

QUITE UNOBTRUSIVELY and without undue publicity or fanfare, a radically new machine has been boring large diameter diversion tunnels for the Oahe Dam near Pierre in South Dakota at a speed of penetration in excess of that possible by conventional drilling, blasting, and mucking methods. Maximum performance reported in the driving of the 25-foot, 9-inch tunnels through shales has been 12 feet in one hour producing 480 tons of broken rock; 58 feet in an 8-hour shift; and 78 feet in two shifts producing 3100 tons. These advances include ring beam supports every four feet, lagged with steel mine ties and wire mesh screen. The wall is so smooth that in looking at it one would imagine peering down the barrel of a shotgun.

The machine is the Robbins Tunnel Boring Machine named after its inventor, James S. Robbins, who conceived the principles required to bore through rock while working on the development of the Goodman Continuous Borer. The well-known Goodman 500 Miner and the Goodman 400 Miner, prototypes of the continuous borer, made a tremendous impact on productivity in the mining of coal seams. A 500 Miner operating in one mine averaged 430 tons of coal per shift over a period of four months at a cost of 54 per cent under that by conventional methods.

The first application of the new machine, which utilizes both roller disc cutters and fixed cutters, was at a coal mine in southern Illinois for the driving of two 3000-foot slope entries. It had been found that the machines first used, utilizing only fixed cutters, would not penetrate certain of the sedimentary starta, and so the disc cutter was developed and tried out successfully. The second application was in the driving of a tunnel under the Arkansas River.

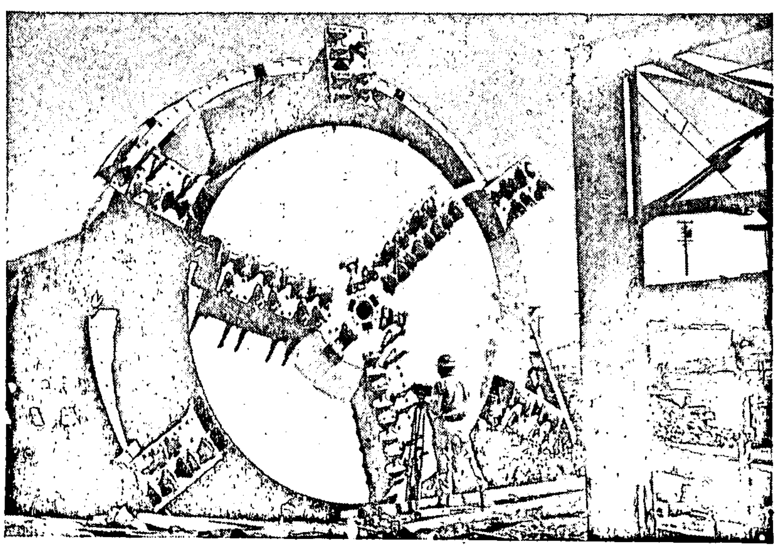
Flood Control Project

The flood control project at Oahe Dam includes the driving of six 1800-foot diversion tunnels under conditions which imposed some serious handicaps for the successful contractor, Mittry Constructors of Los Angeles, who undertook the task. Four of these tunnels have now been completed and a start has been made on the fifth.

One condition imposed by the specifications, which would not have been a problem with a conventional method of driving but which necessitated serious complications of design with a boring machine, was that the diameter of the tunnel had to be reduced by 18 inches after the first 150 feet. In addition, the government required that a rolled H section ring beam be installed to support the walls and back every four feet, the sets at all times to be kept within nine feet of the face. An elaborate mechanical method of delivering and mounting the sets was developed so as to keep pace with the rapid forward advance of the machine. A further complication was added by requiring that part of the tunnel be driven on a gradual curve. With a tolerance of only one inch it was necessary to keep absolutely on line and grade. Humidity in the tunnel has to be kept at 95 per cent to prevent deterioration of the walls, and the resulting fog and wetness add nothing to the ease of operation.

The greatest handicap is that a 2½-foot thick reinforced concrete lining has to be applied within thirty days of the original exposure of any section of the tunnel. Stipulations regarding the manner of doing this work required periodic stopping of the big machine to follow up with the concreting operation. This in part prevented continuous operation for any length of time so that true sustained performance of the machine could not be determined.

The boring machine was built in 8 months in 10 machine shops under a license agreement with Goodman Manufacturing Co. who hold patent rights.



Robbins Boring Machine at Oahe Mine

Operation of Tunnel Borer

The enormous boring head consists of three central cutting arms rotating counter-clockwise (as you look at the face), and six outer cutting arms rotating in the opposite direction so as to balance the tremendous torque. A shield back of the outer cutting elements confines the rock

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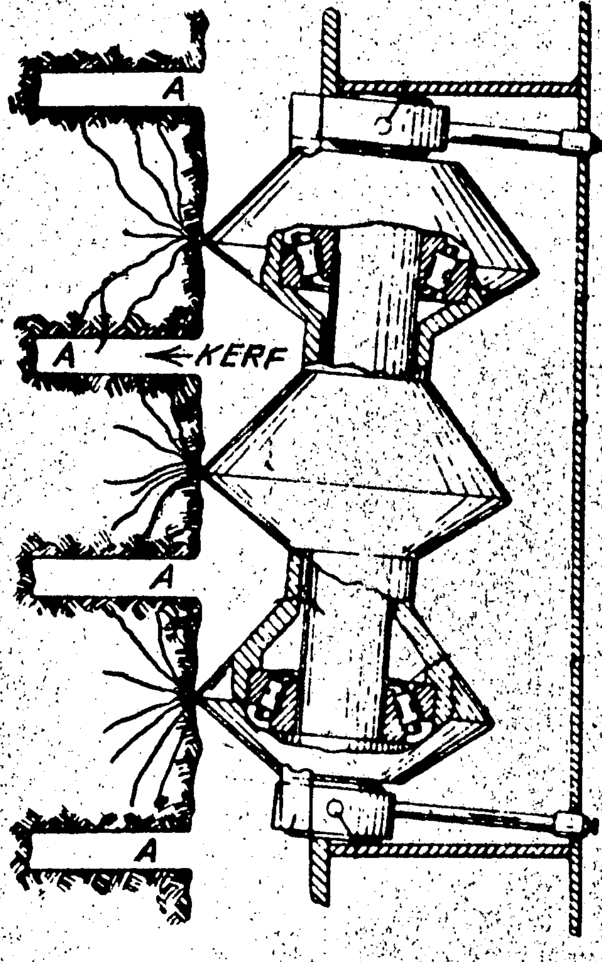
and dust close to the face of the tunnel where it can be picked up and elevated by the buckets of the outer cutting arms and dropped through the base of the buckets onto a conveyor belt.

Cutting is accomplished initially by a series of fixed or drag-type tungsten-carbide bits that travel in circular paths, cutting grooves or kerfs amounting to a series of concentric circles in the tunnel face. (See Fig. 2). The kerfs so formed are 8-10 inches apart and 6-8 inches deep. Disc-shaped cutters mounted slightly behind the fixed cutters simply roll around with the lead edge following the centre of the core left between two adjacent kerfs. Contact of the disc with the rock brings about a phenomenon that is hard to understand without actually witnessing it. The effect however is one of shattering the core to a depth well below the point of contact of the disc as shown in the drawing, and generally breaking the core into large lumps. While no screen analysis has yet been made it would appear that not more than about 40 per cent of the material would pass a 12-inch grizzly. This means that the power consumption is unbelievably low; only 200 h.p. being used in driving a 26-foot, 9-inch diameter even when advancing at the rate of 12 feet per hour and producing 480 tons of broken rock.

At Oahe, the kerfs occupy only 10 per cent of the face area while the disc shatters the resulting core easily. The factor limiting the hardness of the rock that can be penetrated with the present machine is the economic life of the fixed cutting tools. The life of the discs is remarkable in that the unit is simply a mild steel casting. In driving four of the tunnels only six discs were replaced and these through failure of the seals in the bearings rather than through excessive wear of the disc edge.

The whole machine is 90 feet long and weighs 120 tons. The cutters are powered by two 200-h.p. wound-rotor-motors through gear mechanisms. Forward motion is accomplished by hydraulically operated "feet" which propel the borer on tracks and which are driven by a 25-h.p. motor. Diesel generators at the portal supply power for the operation, being stepped down by three 167-kva transformers mounted on the machine. Motor controllers provide short circuit protection and permit centralized push button control at the operators station. Protection of the electrical system is provided by a dead-front panel with circuit breakers and ground relay.

One operator controls the machine from a control panel in an enclosed cab behind the cutters. He can advance the machine and swing it in any direction by means of a small pilot bit at the centre of the inner cutting head. Steel timber sets are brought in by means of a monorail, and then lifted up and placed against the tunnel wall by a specially designed "jig" thus imparting a high degree of mechanization to this operation.



Rotary Cutter Head, Vertical Section of Tunnel Face.

The 29-man crew includes a mining foreman, two surveyors, the boring machine operator, a conveyor tender, a monorail operator, a ring beam crew of five top men and three bottom men, three general labour top men, two general labour bottom men, an electrician, a mechanic, a welding foreman, four welders, and three helpers. In addition to the above crew which works entirely in the tunnel, there is a battery locomotive crew of two men and a variable number, generally less than three, on the outside who are serving the operation.

Recent Operating Data

A recent engineering time study over six consecutive shifts revealed the following interesting data:

Total footage bored—243 feet;

Average advance per shift—40.5 feet;

Average power consumption, 200 h.p. or 45 per cent of capacity;

Fixed cutter bits consumed, 362;

Fixed cutter bits consumed per foot advance—1.5;

Disc cutters consumed—none;

Possible operating time, 3480 minutes;

Actual operating time, 1760 minutes, or 51 per cent;

Delay time, 1720 minutes, as follows:

21 %	due to conveyor system
17 %	due to resetting and adjusting propelling jacks.
15.2%	due to lack of supplies, inability of monorail to handle sufficient material.
12.8%	due to cave-ins of roof and face ahead of ring beams.
10.5%	due to permitting steel roof support beams and blocking to catch up to excavation.
10.1%	due to lunch time
8.5%	due to replacing cutter bits.
4.9%	due to miscellaneous.

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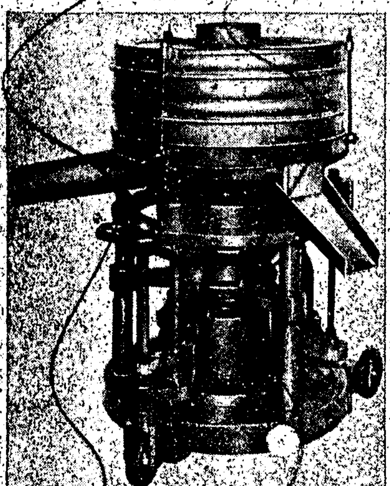
Due to the limitations of the fixed cuttings tools in hard rock and to the remarkable performance of the disc cutters, experiments are currently underway to substantiate a belief held by the inventor that the machine can be adapted to boring through hard abrasive rock like granite and quartz by eliminating the fixed cutting tools and relying solely on the disc cutters. Needless to say, the successful adaptation of this tool to underground development work and even as a production machine would have tremendous impact on the whole mining industry as well as on the construction trade. Even in its present form we sense that some form of revolution has quietly taken place which will have an appreciable and growing effect in rock tunneling through softer rock formations. Studies for instance, have indicated that advances of 100 feet per shift are quite possible under good rock and operating conditions where concreting is not immediately necessary. A coal mine in southern Illinois at the present time produces 8000 tons of coal per day with a total crew including the surface men and the superintendent of 215 men. In this mine there has never been a shot fired.

Mechanical Separation of Columbite



Cascade Machine mobile unit.

ONE OF THE problems which the mine owner has to face is the disposal of the vast quantities of waste material which is brought to the surface in the course of operations, and is in most cases, left to accumulate constituting an eyesore and a waste of otherwise valuable land.

In tin mining however it is known that wherever deposits of tin occur so do also many other valuable ores which can subsequently be extracted from this waste material. In some districts one of these takes the form of columbite which is the largest source of columbium (niobium), a material necessary for the manufacture of electric light filaments, jet engine components and certain atomic equipment. It is worth about £2,000 a ton.

Until recently it has not been possible to find a means for separating this columbite from the other waste material but there is now available a machine which can separate almost any predetermined metallic ore from its surroundings. This machine can however only treat the material after it has been reduced to a powder consisting of particles of uniform size and unfortunately a difficulty arises here inasmuch as columbite is an ore the particles of which when crushed takes a curious form being mostly shaped like minute carrots. This means that using ordinary sieving machines the particles tend to enter the apertures of the mesh pointed end first where they become firmly wedged by the impact of the rest of the material. This results in the screen quickly becoming clogged and unusable.

However quite recently the problem of the mechanised sieving of the crushed material containing columbite has been tackled from an entirely new angle.

Messrs. Russell Constructions Ltd. of London, England, represented in Canada by Bowers Machine Co. have designed a machine in which the vibrations which promote the sieving effect are of a gyratory nature, that is to say, the mesh screen is caused to move in a minute circular orbit in a horizontal plane. This eliminates all bouncing movement in the material being sieved and when applied to columbite the carrot shaped particles are subjected to a dual motion that of rotating and turning end over end. They thus pass readily through the mesh with no sticking or blinding of the screen apertures.

A ¾-h.p. electric motor supplies the power. The screening assembly is mounted in compressed rubber bushes and takes the form of the Russel 'Cascade' unit. In this there are three circular screens superimposed, the whole assembly being housed in a dust tight casing measuring 22 in. in diameter and 11 in. in height. The mesh discs are 19 in. in diameter and have a combined total area of 6½ square feet.

The raw powdered material is introduced at the top of the unit and the gyratory motion causes the material to take a spiral path successively over the three discs. The fine particles which pass through the mesh apertures travel down the central duct of the machine and issue from the spout on the right of the unit while the oversize material which passes over the edge of the discs is collected and passed off via the reject outlet spout on the left of the unit.

The powdered material thus obtained is now uniform in size and is ready for transfer to the separating machine, enabling this to extract the columbite.

My Arthritis is still bothering me.

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No. 5

parts of bit does not happen so often.

• **The danger of twisting off** is always present while rotary drilling because of its high speeds. Furthermore, the formation of keyseats is another frequent cause of fishing operations. While turbodrilling this happens less frequently because the hole is straighter and the stems turn slowly or not at all.

• **For turbodrilling** the most frequent cause of fishing operations is falling, swelling, or flowing rock formations. However, a straight hole, tension loaded drill stem, and very low rotative speeds of the stem reduce this danger very much. Turbodrilling does not create any new drilling difficulties and eliminates most of the existing difficulties of rotary drilling or reduces them to a great extent.

• **Less strain on the rig.** The strain on the swivel and the rotary table is considerably reduced. The mast base vibrates only slightly. This results in a reduced strain on the rig in general.

• **A clean hole.** The lifting capacity of the drilling mud is improved by the higher annular velocity. The drilled particles are of finer grain because of the higher speed of the bit, and can be brought out better.

• **Interchangeability.** The turbodrilling is interchangeable with the rotary-drilling method.

Disadvantages of turbodrilling. If difficult drilling conditions prevail requiring a heavy and viscous mud the turbodrill cannot be applied as long as these special conditions exist.

For turbodrilling the speed of the bit varies between 200 and 600 rpm. Therefore it is possible that certain beds may not be drilled as well as with rotary methods at a bit speed of 50 to 70 rpm. The final answer, however, could only be given after extensive drilling experience.

Strain to the mud pumps. The strain to the mud pumps will be higher because the pumps have to perform more for turbodrilling. For this reason it is necessary to keep the sand content of the fluid as low as possible. For practical purposes a sand content of less than 3 percent by volume is considered good.

Either as general successor of, or as supplement to, the rotary-method the turbodrilling method promises to contribute an important share towards increasing the capacity and rentability of deep drilling. —The End

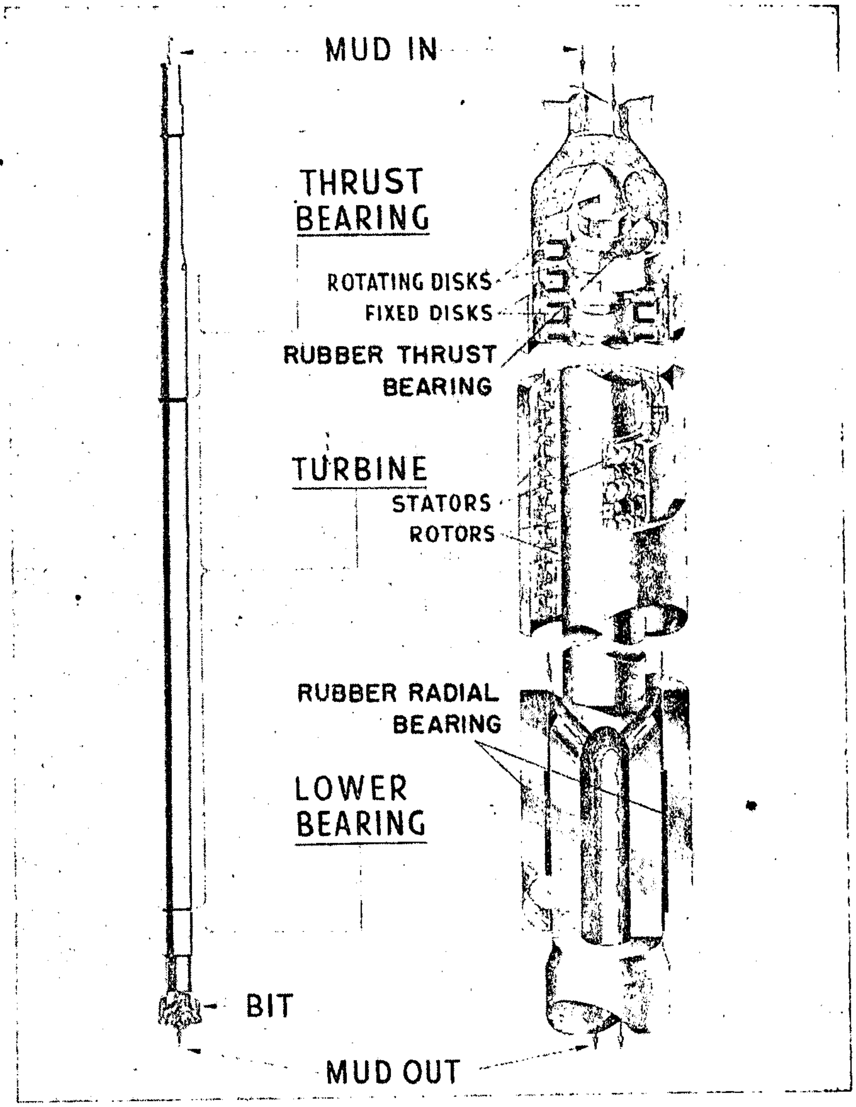

FIGURE 1—Cutaway drawing of turbodrill showing the important components and operational features.

Russian Turbodrills . . . How Good are They?

How do Russian technological advances compare with those of the U. S.? Russian turbodrills now in Dallas will soon be tested against American rotary equipment.

In recent months the drilling industry has become increasingly aware of the possibilities inherent in having a down the hole source of power for driving the drill bit. Scattered and unsuccessful tests have been carried on in the U. S. since 1873, but only recently with reported success of Russian turbodrilling has there been much widespread interest in this method.

Now, tool manufacturers and drilling personnel alike are anxiously awaiting the results of tests presently

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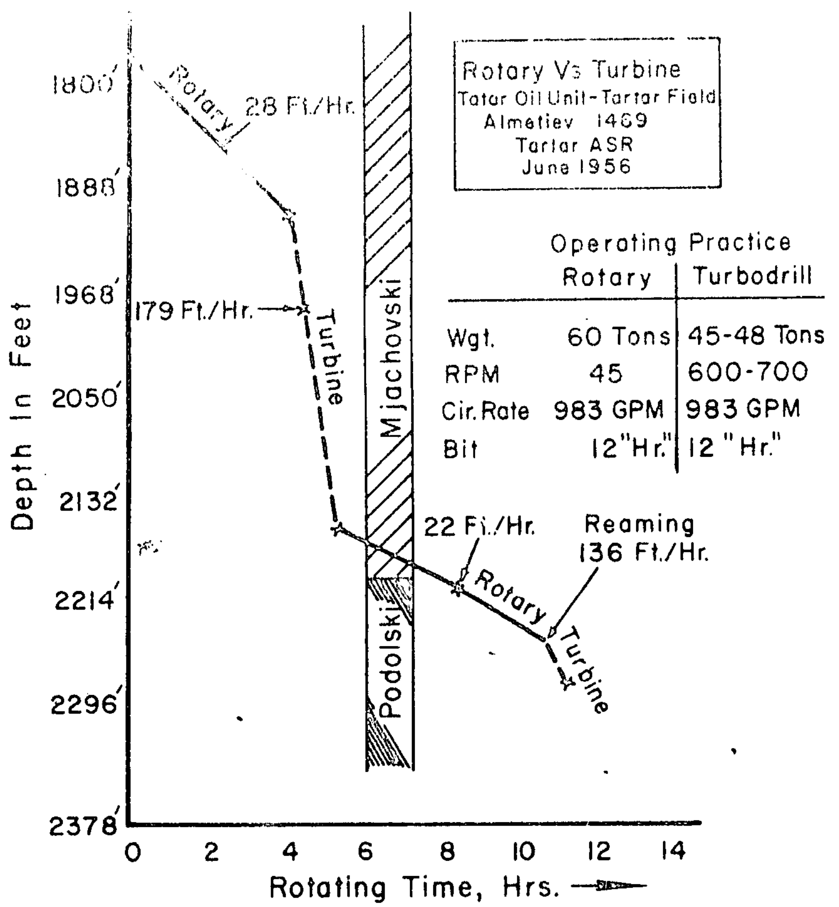

FIGURE 2—Comparison of turbodrill and conventional rotary drilling rates when penetrating the hard Carboniferous formation (equivalent to a Mississippian limestone) in Russia.

being conducted on 40 imported Russian turbines. How and why were these turbos obtained? Are claims made for turbodrilling far fetched and unreasonable or can this method further improve drilling progress here in America?

Most readers are already familiar with earlier turbodrill experiments and some of the results, both here and abroad. Dresser Industries, Inc., first entered the field of turbodrilling when they acquired the EDCO turbodrill in 1950. It consisted of a multi-stage, direct drive, impulse turbine similar to one of the early Russian models. Dresser undertook this development work but when it was completed they found that the power output and efficiency of this turbine were too low for economical drilling.

There were other turbodrills that were tried unsuccessfully but the Russians were the first to come up with one that seemed to work economically and efficiently. In a nation in which the state is omnipotent, there is no question in industrial development of responsibility to stockholders, no necessity for showing an economical operation, no need to show a margin of profit. Only the blessing of the State is needed upon a given project. Once this has been obtained, there is little question of the millions spent upon research; the hundreds of personnel channelled into such a project, or the vast amounts of money spent in experimenting and testing. The State is answerable only to itself, and has no customer problems such as must be faced in the U. S. And, so, the Russian turbodrill development progressed.

The first Russian turbodrill developed by M. A. Kapelyushnikov in 1925 was a single-stage high-speed turbine driving the bit through a planetary reduction gear. Its use was discontinued in 1934 because it was considered less efficient than conventional rotary drilling.

In 1935 a new type of multi-stage direct-drive turbodrill was designed by the Russian engineers but it was not fully perfected until after the war. This was considered such an a great achievement that R. A. Ioannesyan and M. T. Gusman were awarded the Stalin prize for their improvements on the turbodrill. In 1947 the Russians had a fairly good turbodrill and an American industrialist had several meetings with them to discuss the possibility of making a license agreement. They promised to show the tool working in the field but security regulations interfered. It was therefore impossible to conclude an agreement at that time.

The first direct-drive multi-stage turbodrills were equipped with sealed roller-bearings which failed frequently because drilling mud contaminated the lubricating system. The Russians decided that the turbodrill must be "de-refined" into a rough and rugged tool to meet oil field conditions. The result was the development of a rubber thrust bearing (see Figure 1) which is lubricated by the drilling mud and which need not be sealed against the entrance of abrasives.

While the Russians are a practical people operating with a minimum of technical personnel, they carried on research work in a special institute, the All-Union Institute for Scientific Investigation for Drilling of Oil Wells, established for the study of turbodrilling. This institute was equipped with all of the instruments needed for the study of fluid dynamics, cavitation, and the behavior of viscous liquids. The facilities include a small shop capable of turning out a complete turbodrill even to making the steel castings for the rotors and stators. They also have complete heat treating facilities for the thrust bearings.

The staff of about 200 people at the institute includes 30 engineers and chemists and two experts on hydrodynamics. In the laboratory are two dynamometers, a stroboscope and a high-speed motion picture camera for studying the action of drill-bit teeth on the formation. They also have a turbine in a lucite case to study cavitation. In general, their instrumentation is crude but effective. In dealing with the Russians we must not be deceived by their appearance. They look like peasants and they need materials to work with but their technical skill should not be underestimated.

The Russians have developed four

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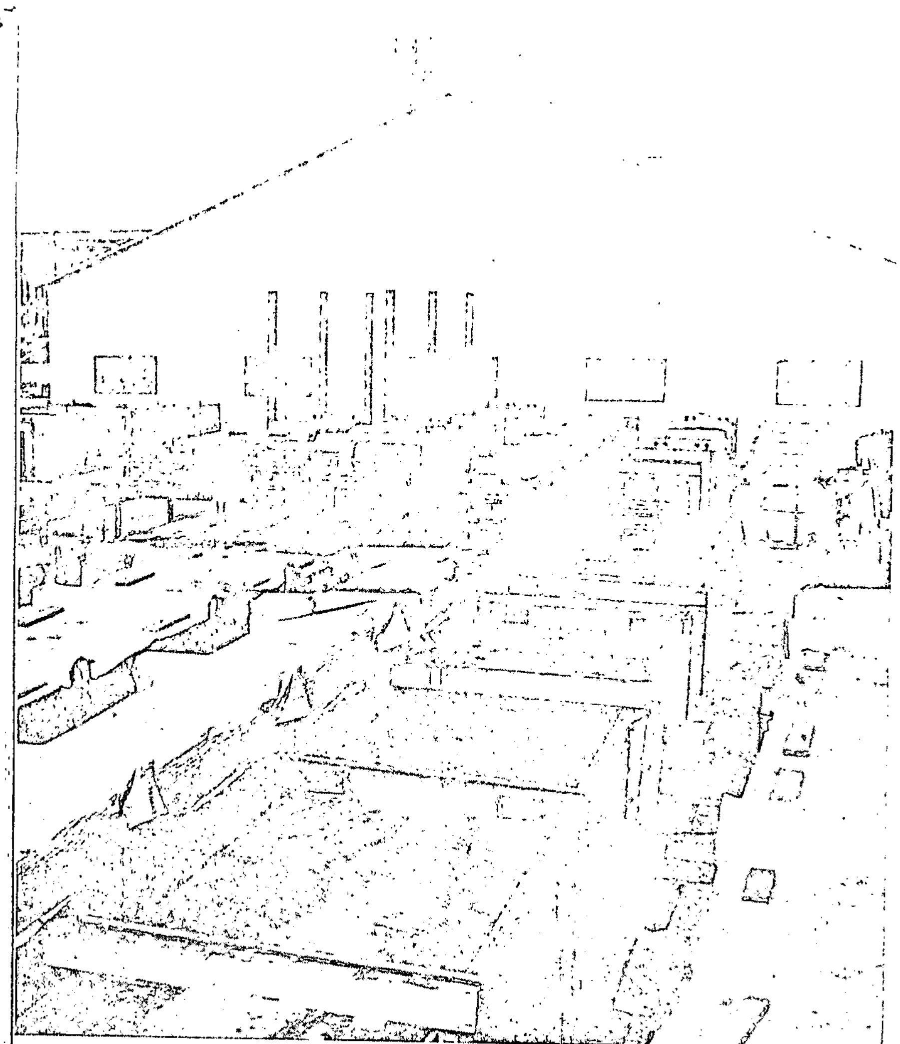

Forty Russian turbodrills in heavily reinforced crates arrive in Dallas at facilities especially prepared for testing and maintenance of the turbos.

sizes of turbodrills in two different basic types. One type, the T12M2, is for driving a regular rock bit while the other, the KTD, has a hollow shaft to accommodate a wireline core barrel. They have also developed a tandem drill, the TS4 which permits putting together two or three turbines to obtain a total of as many as 240 stages on one shaft. These are used in soft formations where high torque and low speed are necessary.

In the Bashkir oil field between Bugulma and Tuymazy in the Tartar Republic, 170 drilling rigs are running, all using the turbodrill. The rapid development of this field is due entirely to the use of the turbodrill. They are drilling wells in eight days that would require 36 days by conventional rotary drilling. The wells in this field are from 5400 to 5600 feet deep and it is hard drilling practically all the way. They use 61 bits per well and average 100 feet per hour. A breakdown of the time spent on the average well is as follows:

Actual drilling time	54 hrs.
Adding pipe	22 hrs.
Pulling pipe	126 hrs.
Total	202 hrs.

A graphical comparison of rotary and turbodrilling in the Tartar Field is shown in Figure 2.

In turbodrilling they carry from 20 to 27 tons weight on the bit which runs at 400 to 900 rpm. Two 400 horsepower mud pumps are used and they operate at 1470 to 1760 pounds per square inch of pressure. With such a rig, and a 5⅝-inch turbine, they have drilled to depths of 15,000 feet. The turbodrills work best in the hard formations which are the most difficult for conventional rotary drilling to penetrate.

An American witnessed a test between conventional rotary drilling and the turbodrill. At the time they were drilling in dolomite at a depth of 1200 feet. The rotary was run at 250 revolutions per minute which is high for this formation. The weight on the bit was 20 tons and the maximum rate of penetration was 4½ feet per hour. In the same formation, the turbodrill with 20 to 24 tons on the bit drilled at the rate of 57 to 75 feet per hour. In both tests the mud pressure was 1470 to 1760 psi and the circulation rate was 950 gallons per minute.

There are three turbodrill repair stations in Bashkir and two in Tuymazy. A running record is kept of each turbodrill including the number of operating hours, when repairs were made, and the extent of the repairs. At one of these repair stations a random inspection of a number of turbodrills returned from the field was made and it was found that they did not need any attention except thrust bearing repairs. This was most surprising because in the earlier models of turbodrills designed in this country the greatest concern of the engineers was erosion of the turbine blading by the drilling mud. The Russians have apparently found a solution to this problem through extensive research and experimental work.

The solution of the problems involved in the design of a turbodrill depend so much on extensive field experience and data gained therefrom that it would be very costly and time consuming to build a successful turbodrill without this experience. Earlier plans called for bringing Russian drilling personnel into this country to eliminate the delay in acquiring this needed experience.

One of the important problems associated with turbodrilling is the design of the rock bits. Since the turbodrill runs at speeds ranging from 500 to 900 rpm as compared with rotary speeds of 50 to 250 rpm the bearings in the cutters of a standard rock bit invariably fail before the teeth are worn out. At the time Dresser was working on the Edco turbodrill their bit designers had no ready answer to this problem and said it would require extensive research to develop a satisfactory bearing for high speeds. The Russian answer to this problem can be obtained through an

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Drilling crew from Gardner Brothers prepares to run a 10-inch KTD turbodrill in the hole with a four-cone coring bit.

exchange of information on bit design. Such an exchange of information would be of greater advantage to the U. S. than to the Russians because our design data on bits for low rotating speed and heavy weights would be of little value to the Russians for use on their turbodrills. On the other hand, we have no design data or field experience on bits for operation at high turbodrill speeds.

It might be asked why the Russians are now willing to make their turbodrilling technology available to us. The answer seems to be that their vanity got the best of them because ever since the World Petroleum Congress in Rome last year they have been pressing to have the turbodrill tried elsewhere in order to get credit for their accomplishments. In time the turbodrill could revolutionize the oil industry in the U. S. as it has in Russia, where 70 percent of all oil wells are drilled and it would be a tragic mistake not to take advantage of this opportunity.

Consequently, the American concern entered into negotiations with the Russians and subsequently with Establissements Neyrpic for obtaining a licensing agreement for the manufacture and use of turbodrills in the U. S. and Canada. After many discussions and much delay 40 turbodrills representing three different types; the T12M2, in 6⅝-inch, 8-inch, 9-inch and 10-inch diameter sizes; the T54 in 5-inch, 6⅝-inch, 8-inch and 10-inch diameter and the KTD coring turbodrill in 8-inch and 10-inch diameter size were received in Dallas.

No time was lost in establishing a test turbodrill station and drillsite at one of the company's plants in Dallas. A small portable rig with a large independently driven triplex pump was moved in, and indoctrination tests for company personnel were under way. A trained drilling crew from a contract drilling firm is being used to operate the rig and to acquaint drilling and engineering personnel with the operating characteristics of the turbodrill. These preliminary tests are not designed to put the turbo through its paces as yet.

At the present time drilling and coring techniques are being tried under controlled conditions. A typical test while using the T12M3-10-inch with a 12¼-inch soft formation bit consisted of applying about 20 tons of drill collar weight to the bit and an indeterminable amount of weight due to the applied hydrodynamic head. Circulation was approximately 630 gallons per minute at 1350 psi. Pressure drop across the turbine at these rates is approximately 6700 psi.

One of the many characteristics of this drill that must be determined by tests is a means of calculating the amount of weight applied to the bit by the hydrodynamic action of the drilling fluid. It is necessary to keep the thrust bearings as nearly balanced as possible at all times, and knowing this weight can be quite important. If the down thrust, or weight, due to the hydrodynamic force, and the weight of the collars, is too far in excess of the weight applied to the bit then the top of the thrust bearings will wear excessively. If the reverse is true and the upward thrust is greater, then the underside of the rubber covered thrust bearings will wear excessively.

Upon completion of these orientation tests the turbodrill will be taken to the field, where it will be given comparative tests with regular rotary drilling in all types of formations under all possible conditions. Marketing or leasing arrangements have not been decided upon at this time, but it is hoped that the turbodrill will take its place in the drilling industry sometime in 1957. It is through these field tests and only through these tests that the big question of their comparable performance to standard rotary drilling will be answered.

ACKNOWLEDGMENT

Appreciation is extended to Dresser Industries, Inc. for their assistance in obtaining photographs and data for this article.

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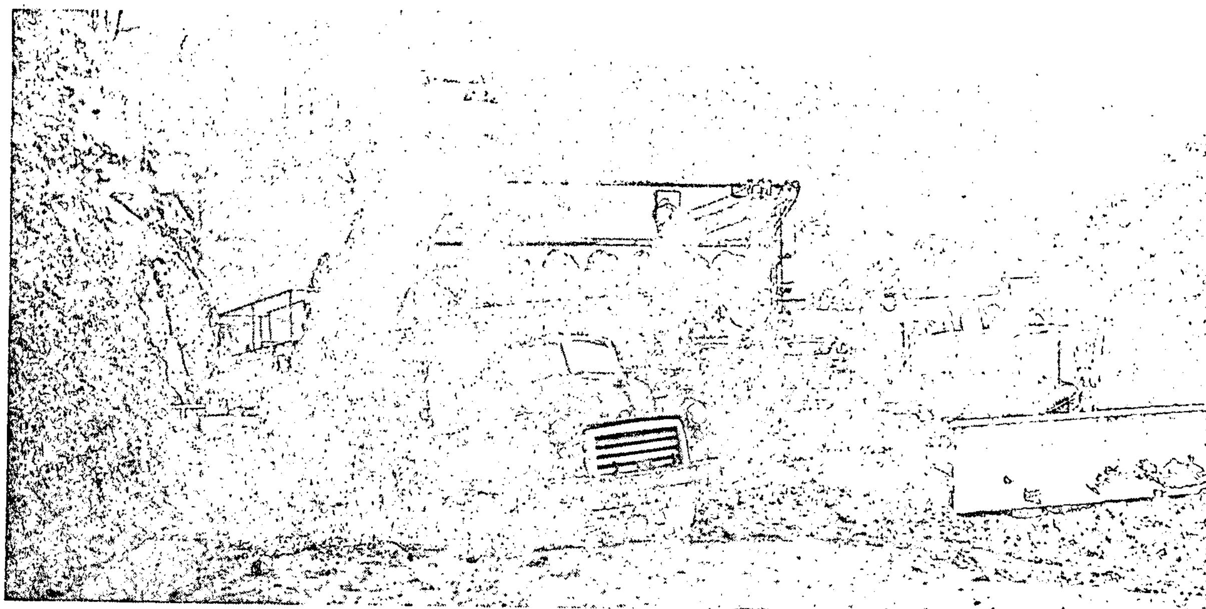
No. 6

Auger Mining in West Virginia



A view of the auger from the discharge side

Bitner Fuel Uses 48-in. Auger to Mine 700 Tons of Coal Per Shift

By GEORGE W. SALL

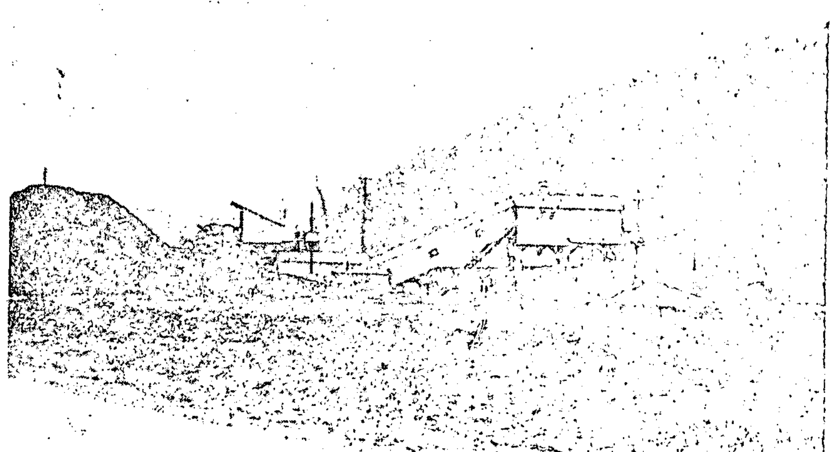
IN recent years strip mine operators have been given a new tool in the never-ending fight for more coal at lower costs. At first this tool, the coal auger, was considered merely an adjunct to other stripping operations—an adjunct which permitted the strip operator to mine coal from fringe areas that would otherwise be left unmined. Now, however, augering has developed to the point where many coal operators gear their entire stripping operation to the auger. There is no denying that auger mining is rapidly coming of age.

Working in Pittsburgh Seam

One company that has taken full advantage of the coal auger is the Bitner Fuel Co., which operates strip mines in the area around Jacksons Mill, W. Va., about 30 miles south of Clarksburg. The company has on its property about 40 miles of Pittsburgh coal outcrop and 25 miles of Redstone outcrop. Between 26 and 28 miles of the Pittsburgh outcrop has been stripped; the rest is untouched.

Both coal seams are found only in the tops of the hills which dot the countryside. Present mining is in the Pittsburgh seam only. In time the Redstone will be stripped or augered wherever possible, but the presence of a great many clay veins make it uneconomical to mine in several areas.

The seam now being mined, the Pittsburgh, runs a consistent 54 to 56 in. thick over the property. In the stripping operation overburden is being moved by a 1201 Lima, high-front shovel having a 2½-cu yd bucket. A Galion Grader follows the stripping shovel to clean the coal seam off and a ¼-cu yd Lorain shovel is used to load coal. The grader is also valuable for maintaining roads, an operation too often slighted by strip mine operators. As a general rule the terrain is such that two cuts can be made before the overburden becomes too heavy for economical handling by present stripping equipment. The average highwall left is between 50 and 55 ft high.



Coal is hauled three miles by truck to a tipple on the Baltimore & Ohio Railroad

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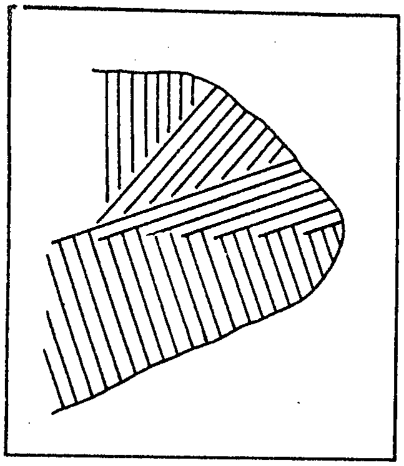
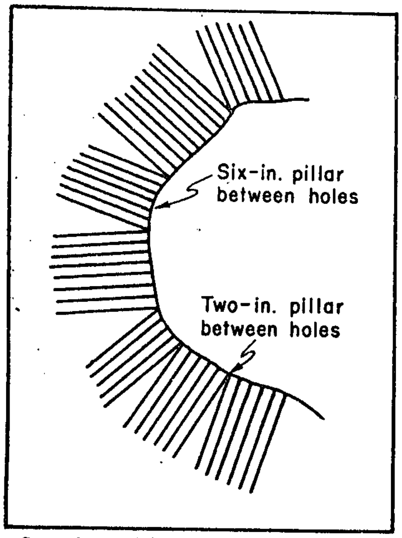


Blocking on outside turns allows for maximum extraction



Sets of parallel holes are used on inside turns

Preparing the Bench

To be prepared for augering, the pit must be at least 50 ft wide since Bitner Fuel is using a Compton Model 48 auger which has a length of 48 ft. To allow trucks to bypass this machine in working position the bench has to be a minimum of 60 ft wide.

Another step in preparing the pit for augering is to take up about six in. of the clay underlying the coal seam. This is bulldozed away and allows more freedom in lining up the auger with the coal seam.

Although the coal is only 54 in. thick, Bitner is using a 48-in. diameter auger. According to accepted practice this is too large—they should only be using a 42-in. auger—and they should pay the penalty in short holes. The coal company calculates, however, that if it can maintain a drill hole depth of 125 ft with the larger auger, more coal and a better rate of recovery can be had from the property than if a 42-in. auger was used. Over the past year hole depth averaged 178 ft, well over the economic cutoff point.

Although the Redstone seam is thick with clay veins, they are relatively few and far between in the Pittsburgh coal on the property. When encountered they are drilled through with the auger. As soon as this material starts feeding out of the hole though, it is loaded out separately and dumped on the ground at the tipple. Any lump coal is picked out for house coal.

Positioning Auger

When lining up for operation, the auger is set to enter the coal about three in. off the bottom. This leaves from three to five in. of coal at the top of the seam. Assuming a level coal seam, the auger is also angled up about two degrees. If the seam dips or rises, a compensation is made to keep the same two-degree difference between the plane of the auger and the plane of the coal. A spirit level, calibrated in degrees, is used to line up the bed of the machine. The calibrations on the level make this job easier.

Whenever possible drilling is on the butt cleat or at least on ¼ butts. This is done for two reasons: first the coal cuts easier on the butt than on the face cleat; second more lump coal is produced when drilled on the butt.

The deepest holes being drilled are 208 ft. This depth hole takes, in addition to the 8-ft cutting head, eight 25-ft augers—all that can be racked on the machine. Average drilling time, from the time the hole is started until the hole is completed and all augers are retracted and racked, is in the range of 45-50 minutes—that is for a full hole. It takes four to five minutes to move the auger to the next set up and seven to eight minutes to level up the auger for drilling.

Making Turns

Turns are the bane of any auger operation, and with the coal seam lying in the tops of hills deeply cut with ravines, Bitner Fuel has its full share of turns. The problem, of course, is to get as much coal as possible without having to drill short holes to get it. Bittner meets this problem by a process it calls "blocking the turns." As the auger comes into an outside turn, the holes are shortened an auger length at a time, but kept parallel. When the last hole is drilled (it will only be one auger length in depth) the machine is slewed so that the next full length hole is drilled parallel to the ends of the shortened holes. Hole depths are again shortened one auger at a time for the next several holes. This can be continued on around the turn if desired or the auger can be positioned so that subsequent holes drill into the freshly drilled areas. The shape of the turn and its size will dictate how the turn is completed.

On inside turns holes are augered in parallel sets. The number of sets and the number of holes in a set are also determined by the size and shape of the turn. W'·n a change in direction of the auger is made from one set to the next, the pillar is narrowed down to two in. at the face.

Winch Auger Into Position

All moves are scaled to an accuracy of one in. A steel pin is driven into the ground by the pontoons on the side of the machine away from the direc-

An end-on view of the auger at the completion of its work at one pit. From this location, the auger was trucked to a newly opened pit 1½ miles away

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tion of travel. The advance is measured from this point. It is during this time that the newly augered hole is inspected by the auger foreman in readiness for the next set-up.

When moving from a completed hole to a new set-up, the auger is winched ahead instead of being towed. The coal company bought a second-hand D-8 tractor at a considerable saving and equipped it with a Hyster winch. Although the tracks on the D-8 are worn, it has enough traction to stay in position on most of the moves. If the pull gets extra hard, the operator merely spins one track at a time (he can do this because he is pulling against the winch cable) and digs the D-8 down. In this position it acts as a giant deadman and is well anchored against any pull it can exert on the 45-ton auger.

The winch also comes in handy for recovering lost augers. This is not often necessary. When it is, the auger has usually been lost because of a broken coupling pin, not because it was caught in a squeeze.

BITNER FUEL COMPANY

AUGER MINING REPORT

MINE Millstone

MOTORMAN — HRS — DRILL — DATE

HYDRAULIC OPERATOR — HRS — SURFACE OWNER — SHIFT

HELPER — HRS — COAL OWNER — AUGER NO

HELPER — HRS

TRACTOR OPERATOR — HRS — REPORT NO

No. Holes	Drilling Time	Depth of Hole	Time Delayed	Supplies: Fuel	Oil	Grease	Supply	New Bits	Old Bits	Reason and Remarks
1-6	50	156'	Changing time on bits — 10 mins							Old Mine
2-6½	50	169'								Old Mine
3-8	70	210'	Wait on trucks — 25 mins							
4-8	70	210'								
5-6	50	156'								Hit Bottom
6-8	70	210'								
7-8	70	210'								
8-8	65	210'								
9-8	70	210'								

OTHER REMARKS.

Records are kept of drilling time and delays for later study and analysis

Crew Size

A five-man crew operates the auger. The importance of selecting the crew cannot be overemphasized. To a large degree it is their ability to work together as a team, and their willingness, that determines production. Bitner Fuel has found it advantageous to hire young men without coal mining experience as crew members. Only the foreman has had deep mine experience. In addition, there is a general superintendent of augering who has charge of planning and reclamation in addition to overseeing the auger operation.

The five-man crew averaged 700 tons' production per eight-hr shift from June 30, 1954, to December 1, 1954. Their best day's output was 1050 tons in a nine-hr shift—a lot of coal from one machine.

Careful and complete records are kept of the operation. This includes listing the number of augers used in each hole, the depth of hole, drilling time, an explanation of delays and the reasons for short holes.

Haulage

Bitner Fuel has contracted its coal hauling on a tonnage basis. Because haulage road conditions are extremely important, the company will only allow tandem trucks to work for them. These trucks, with their greater tire area to carry the load, are not so apt to tear up the haulage roads during wet weather. The company also likes to have trucks on the job that will hold an auger's length of coal—13.4 tons. When this is the case, truck changes can be made at the same time that auger sections are added, and losses in production time are kept to a minimum.

To further cut delays, the company has designed a chute, for installation at the discharge point on the auger conveyor, which can feed coal to the left or right. Operated hydraulically, it will allow two trucks to be in loading position at one time. This will eliminate the three to four-minute truck change time and mean a considerable increase in production time over a long period, assuming, of course, that there are always trucks available.

Realizing that the mined coal is not worth anything until it reaches a market, company management has placed emphasis on good haulage roads. This emphasis has paid off. They have worked when other strip mines in the area haven't because trucks couldn't get in or out of the pit. Drainage is the big problem, and the roads are kept well ditched. A grader is used to keep travelways free of big holes and well crowned. Access roads are surfaced with limestone, where needed, into the pit. Haulage is certainly a most critical part of an augering operation and its importance should not be slighted by poor engineering or lack of maintenance.

48-inch holes and 6-inch pillar in the Pittsburgh seam

Maintenance

Equipment maintenance is handled by two mechanics. All equipment, including reclamation equipment, is greased at the end of every operating shift. Repairs are made, when possible, on the off shift, or when a particular machine can be taken away from its job. In addition to the mechanics, a welder is used for roustabout work. One of his duties is to hardface the outside scroll of the cut-

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ting head and the inside breaker. This is a more important step than might be first considered. The cutting heads, of course, are cylindrical in shape and protected by a scroll which furnishes the riding surface as the coal is drilled. It is almost impossible to make the cutting head perfectly cylindrical in the shop. Through use, though, the head is gradually worn down to a true cylinder. A close check has to be kept on the wear of the head during this break in period. If the protecting scroll should wear thin enough to allow the shell of the cutting head to rub against the coal, the head would soon be worn through. By building the scroll up for its entire length with an even bead of hard weld when it shows wear, the cutting head shell maintains the protection of the scroll.

Bit Changes

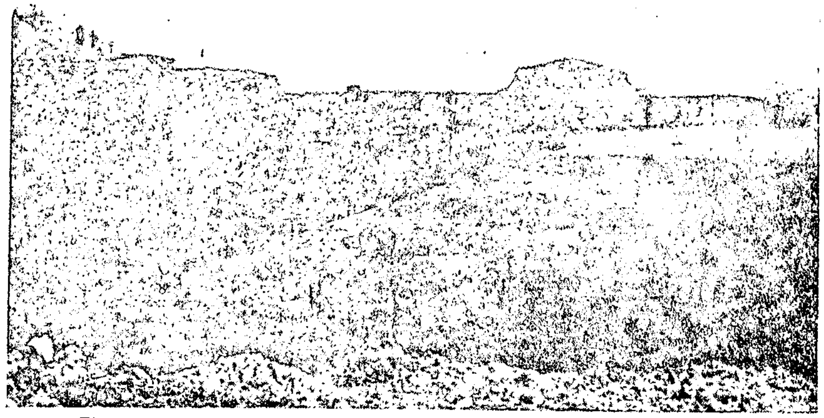
Kennametal tungsten carbide cutting bits are used. Bits on the auger are inspected after every hole and any damaged ones are replaced. During the first week in March, 1500 tons of coal were augered at one stretch without one bit having to be replaced. Bits are reconditioned after use by a commercial bit grinding service.

Bitner Fuel has replaced the No. 8 cutting bit recommended by the auger manufacturer with a No. 7 bit. The gauge of a No. 8 bit is 1½ in. and the gauge of a No. 7 is 1¾ in. They, therefore, are getting a hole ¼ in. larger in diameter, giving greater clearance for the cutting head and the augers. The larger hole has one disadvantage, it will wander more. This has not, however, appreciably affected operation of the auger. When real hard coal is encountered, the No. 7 bits are replaced with No. 8's.

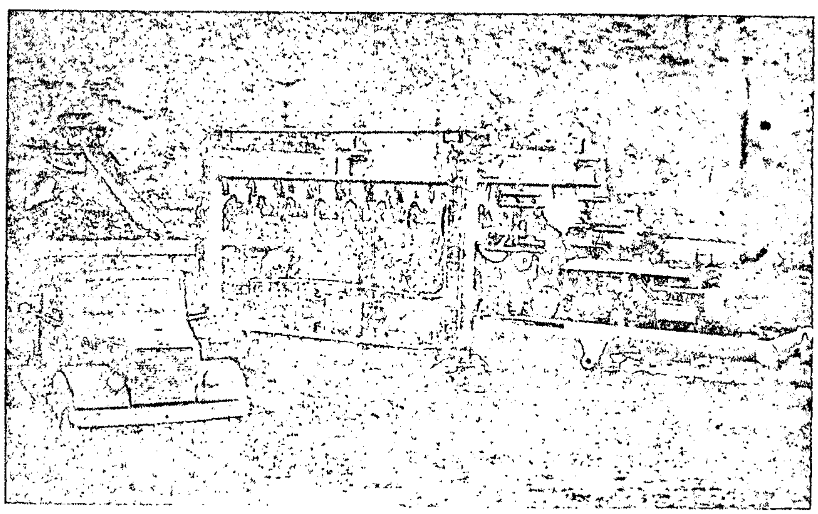
In addition, the coal company is grinding the shoulder of the bits down to the place that the clearance angle is increased from 7° to 15°. While this does not leave as much metal to protect the carbide tip, it does reduce the drag and the company has experienced a 150-200 psi reduction in drilling pressure. Usual drilling pressure is now 1200-1500 psi.

Land Rehabilitation

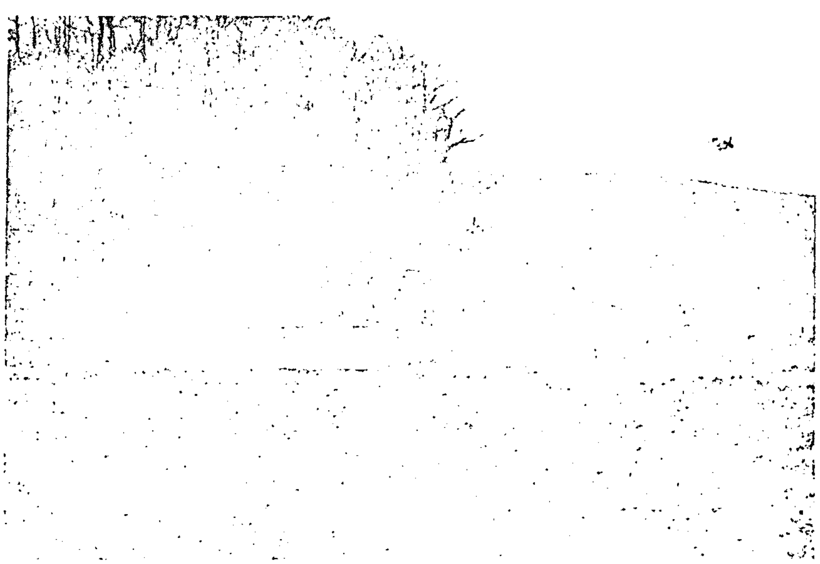
West Virginia law requires that strip mine operators back fill to the top of the coal. Two D-8 bulldozers are kept on this work steadily by the company which goes beyond just backfilling. Displaced overburden is graded to the point where farm machinery can travel it. As backfilling is completed, the land is turned over to a farm subsidiary of the company which seeds the new land in clover or plants Black Locust. The farm subsidiary also manages stock farms on the coal properties bought up by the [illegible] company.



The two coal seams lie in the tops of the hills which dot the countryside



Precious minutes can be saved if trucks are changed at the same time augers are



Two D-8's are kept busy backfilling and grading displaced overburden

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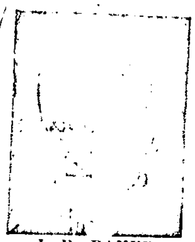
No. 1

JET PIERCING

JOHN R. BAKER

JOHN R. BAKER, B.A.Sc., P.Eng.



J. R. BAKER

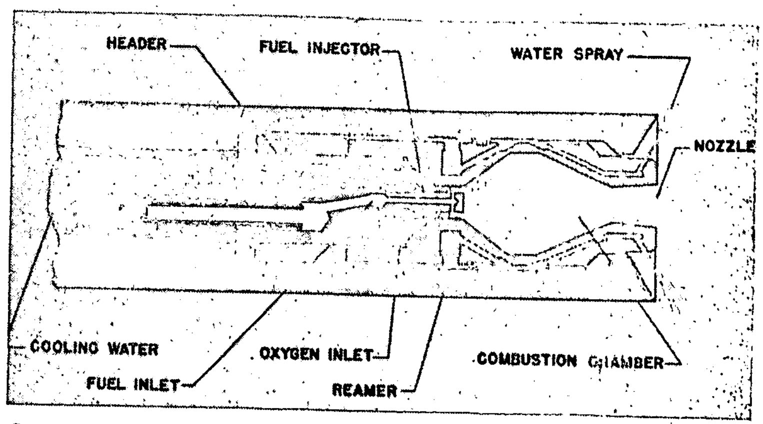
Mr. Baker is assistant to the sales manager, Gas Products, Linde Air Products Company, Division of Union Carbide Canada Limited, Toronto. He graduated from the University of Toronto in 1949 with a degree in Mechanical Engineering. He has held various positions with the Linde organization in the process development and sales engineering fields; and has had wide experience in the application of welding in industry. Prior to his present position Mr. Baker was Assistant Manager, Central District.

Mr. Baker is a member of the Association of Professional Engineers of the Province of Ontario, and the American Society of Mechanical Engineers, Ontario Chapter.

THE ST. LAWRENCE SEAWAY has brought sharply into focus many new industrial developments, not the least of which is an application employing the rocket motor principle. This principle as developed by Linde Air Products Company, Division of Union Carbide Canada Limited has resulted in a process called "Jet-Piercing."

Jet-piercing is being used extensively by United Waterways Constructors Limited, a company formed by a group of Canadian construction firms to undertake work on the St. Lawrence Seaway. United Waterways Constructors is an association formed by Angus Robertson Company Limited, H. J. O'Connell Limited, Foundation Company of Canada Limited and Pentagon Construction Company Limited — all well-known names in the Canadian construction field. The company is operating at Melocheville Quebec a short distance from Beauharnois and is jet-piercing blast holes at the upper Beauharnois lock in a $14,000,000 contract calling for the removal of 3,000,000 tons of rock.

The biggest problem confronting the engineers of the United Waterways Constructors Limited is the removal of rock. The rock which has to be removed at the upper Beauharnois lock is called "potsdam sandstone", a fine grained, grey-white, quartz sandstone with concentrations of heavy residue minerals which frequently give it a banded appearance. This extremely hard and abrasive mass of rock has to be drilled, shot and removed. This drilling problem was solved by Linde Air Products Company, with the introduction of jet-piercing.



Cross Section of a typical suspension piercing burner is shown here. The burner configuration in this instance conforms closely to classical rocket design.

What is Jet-Piercing?

Jet-piercing uses thermal energy in the form of a flame to produce holes in many types of rock. This form of energy contrasts with the mechanical energy utilized in churn-drills, rotary drills, and jack-hammers. The jet-piercing flame is produced in a rocket type burner, thermo-dynamically similar to the rockets being developed for military use. A liquid hydro-carbon fuel such as kerosene or a low viscosity fuel oil is combined with high-purity oxygen in the burner to produce a flame having a temperature in excess of 4,000°F. In addition to this high temperature the gas velocity of the flame is about 6,000 feet per second — more than five times the speed of sound.

When this flame impinges on certain types of rock or ore it causes a thin layer of rock to expand sharply and break away from the base material. The dynamic action of the Jet blows spalled rock out of the path of the flame, exposing new rock. This flaking away of rock particles is called "Spalling" an dis the principle on which the Jet-Piercing process is based.

In addition to the flame another factor, water, is essential to the Jet-Piercing process. Water serves three purposes:

1. It acts as a coolant to preserve the combustion chamber and nozzle of the burner.
2. It quenches and makes any material in the rock brittle that may have become fused by the flame.
3. A large portion of the water turns to steam which carries the sand and chips out of the hole.

The jet-piercing flame represents one of the highest concentrations of energy available to industry. The mechanical energy equivalent of this flame at its highest velocity is equal to about 500 h.p. based on diesel engine efficiency, yet this energy is contained in a flame not more than 18 inches long and 2 inches in diameter. The depth of the hole that can be pierced by this process is limited only by the length of hoses (carrying fuel, oxygen and water) that can be lowered down the hole and still maintain proper fluid pressure at the burner. The deepest hole pierced to date is 180 feet, however, there is no indication that this is the limit.

Applications

All rock formations do not pierce equally well with a jet flame. Piercing

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speed varies according to the spallability of the rock. Some formations do not spall and in these cases melting occurs in the rock. Quartzite, sandstones, granite and granite-like rocks and dolomite are practically 100 per cent spallable. Taconite and specular hematite are also excellent "spallers." Diabase traprock and some low silica and coarse-grained granites have a tendency to melt. These formations can be pierced by a jet flame, but at slower rates than the more spallable rocks.

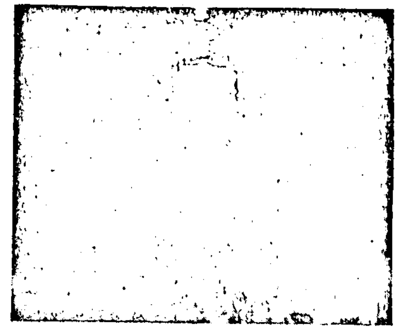
Jet-piercing has made enviable records in certain types of ore including the hard abrasive low grade ore known as magnetic taconite. In the United States at Babbit, Minnesota for instance, 176 feet of 7½-inch diameter blast holes have been made during a single shift. This is more than 10 times the footage made by the best churn drills. Another type of mechanical drill made only 30 feet of 5½-inch hole per shift in similar ore. This latter drill has an average bit life of 76 feet as compared with the jet-piercing burner life of more than 3,000 feet of hole.

These facts and figures do not mean that jet-piercing will displace other methods of drilling for all rocks and ores. Many materials are drilled more economically by methods other than jet-piercing.

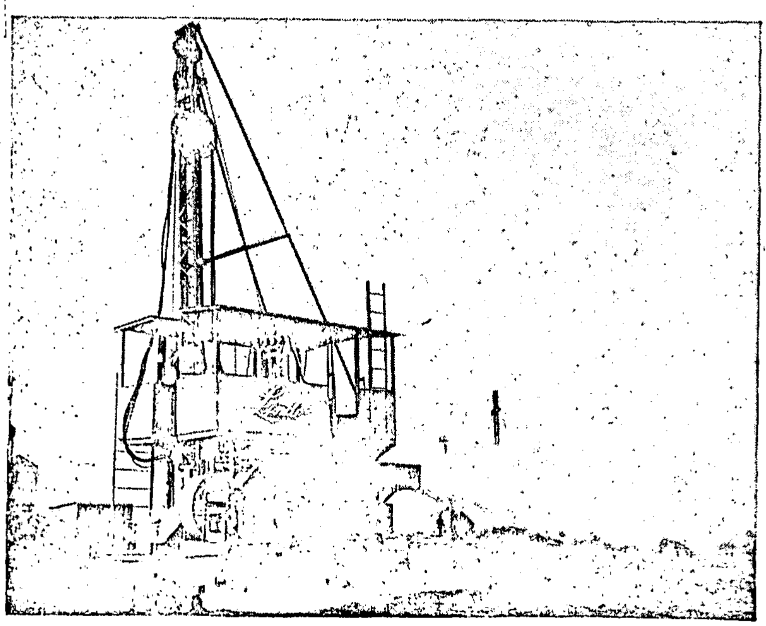
In a crushed stone quarry for example, the objective is similar to that in the mining of iron ore — break the rock or ore into chunks so it can be handled by a scoop or shovel. A fast, economical method for getting well-fragmented rock is available to the quarryman in jet-piercing. In one instance blast holes in granite were produced at a rate of 34 feet per hour and as much as 195 feet of hole in an 8-hour shift.

In mining ore or crushed stone, the condition of the product is not as important since all of the material is removed with the handling equipment available. In the quarrying of dimension stone however, it is most important to obtain large regularly shaped pieces of granite or other stone. As sections of stone are cut away, high internal stresses appear in the base rock. The quarryman's main problem is removal of these stresses — with the least amount of damage to the stone. Jet-piercing in this application is not used ot make blast holes but is used to relieve internal stresses.

Stress relief is accomplished by making a row of holes in the stone, each being about seven inches in diameter. An eight- or nine-inch web or brace of stone is left between the holes. After several holes have been pierced stresses in the rock crush the braces. This leaves an undisturbed block of stone free from internal stresses. By leaving wider webs between holes collapse of the stone mass can be closely controlled. Jet-piercing makes holes in dimension stone at an average speed of about 25 feet per hour. By this application of the jet-piercing principle, loss of valuable stone is kept to a minimum.



This illustration shows the flame of a suspension piercing burner above the hole. Directly below the hole is a casing pipe which is used to prevent excessive washback into the hole when a hole is started in a hollow or depression. With this type of rocket flame piercing speeds in spallable formations have been known to exceed 50 feet per hour.



Linde jet-piercing burner shooting flames into the earth at St. Lawrence Seaway to speed production of blast holes for removing millions of tons of rock. The revolutionary development cuts rapidly through rock and produces such holes up to 10 times faster than conventional drilling methods.

The Development and Scope of Jet-Piercing

Flames compact in size and of extreme high temperature and ever increasing intensity have been used throughout industry since the turn of the century. The first of such flame to be introduced was oxy-acetylene which was used for welding, cutting, heating and heat-treating steel. Some of the other important flames which were developed later are the air natural gas or air oil flame used in the open hearth furnace for steel making, the natural gas-air or propane-air flame for heat-treating furnaces, and the oxy-propane and oxy-natural gas flames of fire finishing of glass ware.

Although the fuel and the design of the burners used to produce these flames differ, they have two common characteristics:

1. The velocity of each of these flames is below the acoustic velocity of the gases used to produce them.

2. The actual ignition or burning of the gases takes place outside the burner itself.

Some ten years ago, experiments were conducted with a radically different jet-type burner. In all burners previously developed regardless of the gas involved, the fuel ignites after leaving the burner as it reaches the atmosphere. By contrast, in the rocket or jet-type flame combustion takes place inside the burner in a reaction chamber. This flame is the heart of the jet-piercing process.

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Process Components of Jet-Piercing

Oxygen

There are several ways in which oxygen can be supplied for jet-piercing. The most economical method of high purity oxygen supply consists of two stages. In this system a producing plant installed near a mine site fills 75,000-cubic foot capacity cylinder trailers to a pressure of 2400 lb. per square inch. The trailers are then hauled and parked close to jet-piercing machines on location. A single trailer carries enough oxygen for eight to ten hours operations. Since all oxygen producing plants are subject to periods of shutdowns for repairs, a liquid oxygen storage unit is used to supplement the production from the plant. Thus, this combined method of supply assures available oxygen at all times, in spite of periodic plant overhaul. In this manner, Linde also makes it possible to provide for increased oxygen demands which may arise from time to time in any multiple, oxygen consuming, operation like jet-piercing.

In other cases, oxygen is delivered in liquid form by specially constructed trucks or railroad tank cars. It is then pumped into insulated storage equipment located on a quarry or mine premises. This liquid oxygen is automatically converted to gas and conveyed by pipe lines to the jet-piercing machine.

Linde Air Products Company, also stores oxygen in cylinders manifolded together which supply automatically at the correct operating pressure of approximately 125 lb. per square inch as it is needed. Pipelines or flexible hoses carry the oxygen to the jet-piercing machine and to the burner. Here, it combines with the petroleum fuel to produce the jet flame.

Oil

Light petroleum base fuel is usually delivered by truck to a tank near the jet-piercing unit. The fuel pump on a jet-piercer draws the petroleum from the tank and pumps it to the burner.

Water

A line carries water at approximately 60-lb. pressure to the burner where it serves the three purposes mentioned earlier.

Latest Equipment

The latest equipment in commercial use is a mobile jet-piercing machine. Mounted on a tractor tread carriage are the operating controls, blowpipe boom from which the blowpipe is suspended and the process fluid supply pumps. This machine makes a minimum diameter blast hole in granite of approximately five inches, and can penetrate up to depths of 200 feet.

Among new features tested in current experimental operations, are automatic electronic controls which start and stop and raise and lower the blowpipe. These automatic features ensure accurate control of piecing speeds and provide greater economy in fuel consumption.

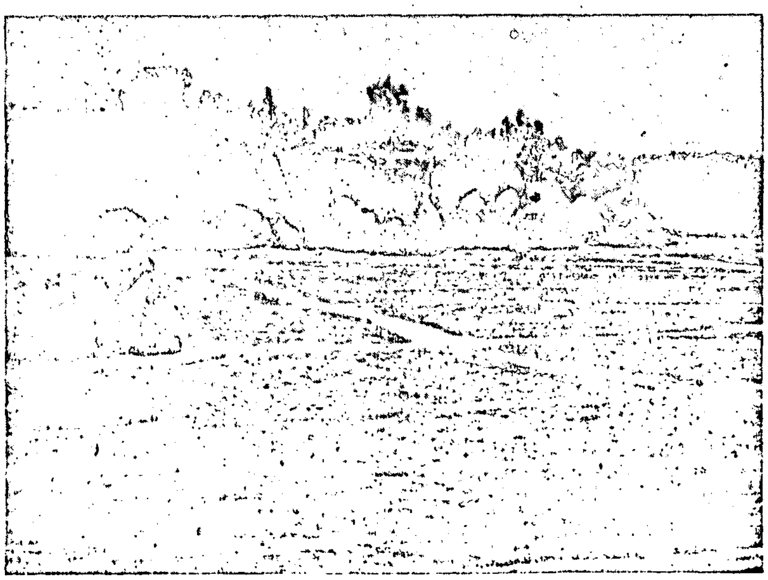
Jet-piercing produces blast holes in taconite, quartzite, granite, syenite and sandstone at speeds up to ten times faster than any conventional drilling methods. However, speed is not the sole advantage of jet-piercing — it is a safe, easy process for producing blast holes and blast hole chambers. Jet flame applications have increased yield per ton and reduced all over costs.

Operational Test Period — Jet-Piercing — St. Lawrence Seaway*

Day	Shift Hours	Drilling Time (Hrs.)	Footage	Operating Factor (Based on Weighted Total shift Time)
1	10	5.9	130	65%
2	10	4.3	60	43%
3	10	5.1	90	64%
4	10	5.3	68	59%
5	10	6.3	56	63%
6	10	4.9	89	49%
7	10	5.7	146	57%
	70	37.5	639	

Drilling Rate — 17.0 ft. per hour
Operating — 57.1%

*At the present time drilling footage runs at close to 200 feet per 12 hours shift.



After the completion of blasthole drilling with suspension piercing equipment, the holes are loaded with explosives and detonated. A typical blast in a granite quarry a few milli-seconds after detonation is shown in this illustration.

Granite Quarrying Operations

Blast-Holes

One of the latest uses of jet-piercing is producing blast holes in crushed stone granite quarries. Producing over 100 feet of hole in one shift is typical of jet-piercing operations in granite. Jet-piercing averages approximately 20 feet of hole per hour and has attained speeds of as high as 50 feet per hour. These high speed performance records of a jet-piercing process compare favorably with older methods of blast-hole making which sometime average no more than 1½ up to 2½ feet per hour.

Average speeds are less in loose rock than in solid rock and it is often necessary to case these holes as in other blast hole producing methods. The jet flame maintains a straight course through loose rock formations.

The jet-piercing process also pene-

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7

trates successfully where "back break" conditions are bad although speeds are slower as in the case of loose rock. Operations are completely successful in spots where it is difficult and sometimes impossible to put down a hole by conventional methods. This enables operators to space blasts exactly as required regardless of rock conditions.

A hand blowpipe first introduced for commercial use in 1950 by Linde Air Products has filled the need for a fast low cost method of putting in small blast holes. It is particularly well suited for "block-hole" operations in taconite, sandstone, and quartzite etc., where speeds average 40 to 50 feet per hour. In granite average speeds are from 22 to 25 feet per hour. The blowpipe weighs only 17 lb. and can reach a maximum depth of five feet. Because it is so light in construction continuing holes much beyond this depth with the hand lowpipe is not practical.

Safe Easy Chambering

The vastly improved method of producing chambers is an important feature of the jet-piercing process. The jet-piercing blowpipe can increase the diameter of a blast-hole to a pearlike chamber at any desired point above or below the quarry floor level — this allows extra explosive charges to be placed exactly where needed. A chamber is produced by making a second pass with the blowpipe or by slowing down its speed in that section of hole where the chamber is desired.

Because of the more accurately loaded blast-holes made possible by chambering "toes" are minimized almost to the point of non-existence, and the fragmentation obtained is excellent. Consequently the amount of secondary breaking required is sharply reduced.

Today, jet-piercing has come of age and is increasing efficiency in the quarrying and mining of numerous rocks, and ores. It has been established as a fast economical method of producing blast holes in extremely hard and normally "difficult-to-drill" materials.

The following is a partial list of materials which can be readily pierced by the jet-piercing process.

Material Pierced	Average Speed feet per hour
1. Coarse Granite	20
2. Ballomitic Limestone	31
3. Quartzite	28
4. Syenite	20
5. Taconite	20
6. Hematite	14

TO EXPLORE AND DEVELOP MINERAL WEALTH OF BOLIVIA

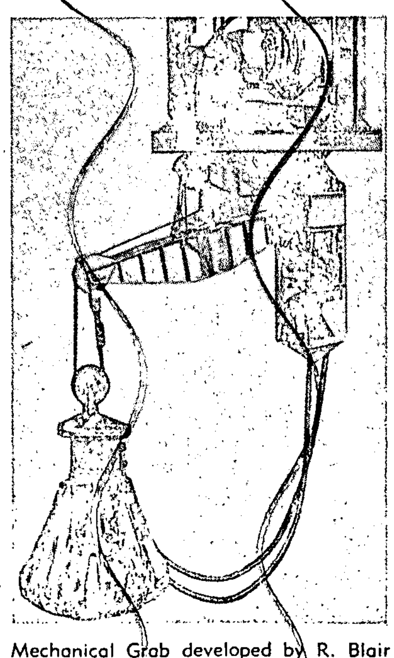
Ventures Limited of Canada and Vitro Minerals Corporation have announced the formation of a jointly owned company, Bolivex Corporation, to explore the untapped mineral wealth of Bolivia.

Officers of Bolivex include Dr. J. D. Bateman of Ventures, chairman of the board; Eugene B. Hotchkiss of Vitro, president; James M. Birkbeck, vice president and general manager; William H. Denne Jr., vice president and secretary, and Paul W. Zeckhausen, treasurer.

Directors include Dr. Potter, J. Carlton Ward Jr., Dr. Bateman, William H. Wright, and Messrs. Hotchkiss and Zeckhausen.

Late last year a program involving large-scale exploration with photogeological studies and aerial and ground geophysical surveys was presented to Bolivian President Dr. Herman Siles Zuazo. The new corporation is expected to commence field work this spring after the detailed arrangements are completed with Bolivian government officials.

Vitro Minerals Corporation is owned jointly by Rochester and Pittsburgh Coal Company and Vitro Corporation of America, a diversified industrial organization active across-the-board in atomic energy from the mining and refining of strategic minerals to the design and construction of nuclear, chemical and metallurgical facilities.



Mechanical Grab developed by R. Blair in South Africa. The device was successfully used in conjunction with a triple-deck stage to establish a world sinking record of 597 feet in a month. Described in October issue CMJ, page 96.

Ventures Limited, an internationally known mining firm, is engaged in mining, metallurgical operations, and research in the United States, Canada, Europe, Africa, South America, and Australia through subsidiary and associate companies.

Canadian Companies in Ireland

According to the latest progress report received from the resident engineer at the Glendalough, Ireland, property being developed jointly by Explorers Alliance and Mogul Mining, "Drifting is proceeding on a 3-shift schedule on the well defined West Foxrock major fault zone.

"The last three rounds pulled were exceptionally well mineralized over an average width of three feet. Galena and sphalerite is uniformly disseminated in addition to definite zones of massive galena within the crushed zone.

"Invariably sphalerite is confined to the footwall and occurs as narrow stringers three to six inches wide. The last 30 feet of drifting was in very treacherous sheared granite.

"Numerous parallel and cross faults within the crushed zone of decomposed granite have caused unexpected heavy falls of faulted blocks of granite. Arching the backs of the drifts will reduce the hazard in future.

"A cross-cut will be driven South-West off the adit near the present face of the drift, with a view to providing adequate space for muck cars, and will also serve as an exploration cross-cut to explore parallel vein structures."

Assay results received with this report show 7.56 per cent lead and 1.0 per cent zinc for the first 35 feet, and 9.0 per cent lead and 1.7 per cent zinc for the next 20 feet, over average widths of three feet.

Metal value of this footage is $29 a ton against estimated production costs of $11 a ton, according to Explorers Alliance managing director J. F. Jupp.

To accelerate assay returns the company is setting up a complete assay office on site, he said. The new office will also be capable of assaying silver and copper values not allowed for in the current reports.

The drifting program is being pressed on a three-shift schedule, and the adit at a second major vein on the same property has reached and is proceeding to re-open the old shaft.

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No. 8

Joy TM 2-1 Twin Borer Miner.

Revolution on the Coal Front

by

RAY FREEDMAN

AFTER months of concerted tests a new and revolutionary device which promises to up coal production at least 75 per cent, was introduced recently in Pittsburgh. It is the TM 2-1 Twin Borer Miner, produced by the Joy Manufacturing Co. of Pittsburgh, Pa.

A working model of the machine was displayed at the Coal Research Conference in Pittsburgh a short time ago. Mining engineers from the United States and Canada were amazed, and not a little awed at what they witnessed. It was the general opinion of all who had seen the machine and learned of its performance, that it would doubtless revitalize the coal mining industry wherever it is used.

Since the average man-day output of coal in the best regulated mines averages about 8½ tons, and the mechanical miner 50 tons a man-day, this spells a mean increase of 600 per cent.

This continuous mining machine uses the boring principle to cut full face at the rough rate of eight tons a minute. Crawler-mounted, it has two boring arms and two sets of twin chains which cut an arched shape for roof control. Its full face cut varies from 5 feet 11 inches to 7 feet 11 inches high and 11 feet 8 inches to 12 feet 8 inches wide. It trams while boring at up to 4½ feet a minute; trams from mined opening at up to 22½ feet a minute. All cutting surfaces retract hydraulically for both roof and wall clearance. All mechanical and electrical components are readily accessible from the outside of the unit for easy servicing. Operating controls are centrally located for convenience. Boring arm diameters can be changed in 4-inch increments from six feet to seven feet by deviating arm end sections of different length, and raising or lowering the main transmission two inches for each change. Additional heights up to twelve inches are cut with the upper trim chain, which is quickly raised hydraulically to the precise location wanted.

Pivotally-mounted at the rear, the rugged main frame may be hydraulically raised or lowered and tilted to each side for properly following the coal seam. This frame and the upper trim chain, weighing a total of 56,500 pounds, act as a unit in resisting radial or torsional shocks created during machine operation. Rear hinging of frame and tractive resistance of crawler treads increase machine stability.

There can be little doubt that the machine is very convincing, as miner or engineer watch the rotating bit (from the outset of operations) cut with a one-two precision movement several inches deep into the coal face. Then, without pause or let up, into the coal circumscribed by the ring, thence cracking it loose.

Six of these precision mechanisms form the cutting head of the machine. They are so set that their rings, each about three feet in diameter, overlap slightly. In the wake of this not too complicated operation a converging system of metal conveying belts, acting similar to a tandem giant maw, "gobbles up" the loosened coal and deposits it gently and without momentum at the rear of the machine while the 30-ton mechanical device slowly crawls forward on caterpillar treads. These treads and the cutters are powered by a pair of separate electric motors.

Once in operation, this novel and practical unit will be controlled by only one man. A push-button remote control box will be slung around his neck. The cost of the machine (which will range anywhere from $75,000 to $100,000) may prohibit its wide use, engineers point out, although it would pay for itself in production alone. The figure of 50 tons a man-day is a realistic rather than fancied figure which tests have shown.

The boring arms of the device will stand up under pressure, for they are heavy steel alloy castings with internally-mounted hydraulic cylinders retracting each arm 11 inches for clearance. The center section of each arm and the cylinders remain the same, regardless of the diameter bored. Only the end sections change appreciably. The boring arm assembly is driven by an 8-inch diameter alloy steel output shaft from the main boring arm transmission.

The two 100 hp. continuous main duty motors provide power through front primary gear trains and universal shafts to both sides of this transmission. The right gear train also powers the lower trim chain. The left gear train on the other hand powers the upper trim chain. The rear of the left main motor shaft drives a variable volume pump, which supplies hydraulic power for traction. A constant volume pump for the other hydraulic machine operations is powered by the right rear motor. Right and left transmissions are shaft-connected for exact timing of boring arms and an equal division of power.

Individual clutches protect all motors and trim chains. A special metered rheostat unit permits the balancing of main motors without overloading.

Nothing is left to chance. The rear conveyor, of conventional design, is 30 inches wide and powered by two 15 hp. motors. It swings 45 degrees to either side, and has a heavy-duty chain with a 2¼-inch pitch. The crawler chain is of twin-link design with a 7 feet 10 inches differential between sprocket centers, and an 18-inch shoe width.

Although the United States Bureau of Mines characterizes the machine as "evolutionary rather than revolutionary," exhaustive tests have shown that the mechanical miner will be worth its weight in coal — if not gold!

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No. 3

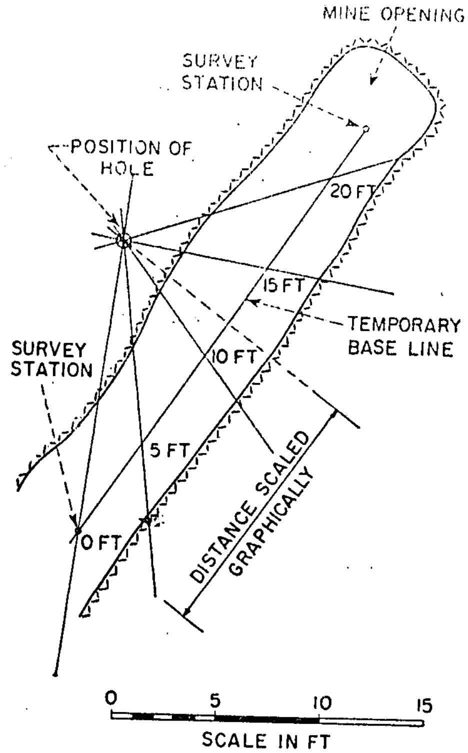

FIG. 1. BEARINGS PLOTTED ALONG survey station lines indicate position of deviated hole.

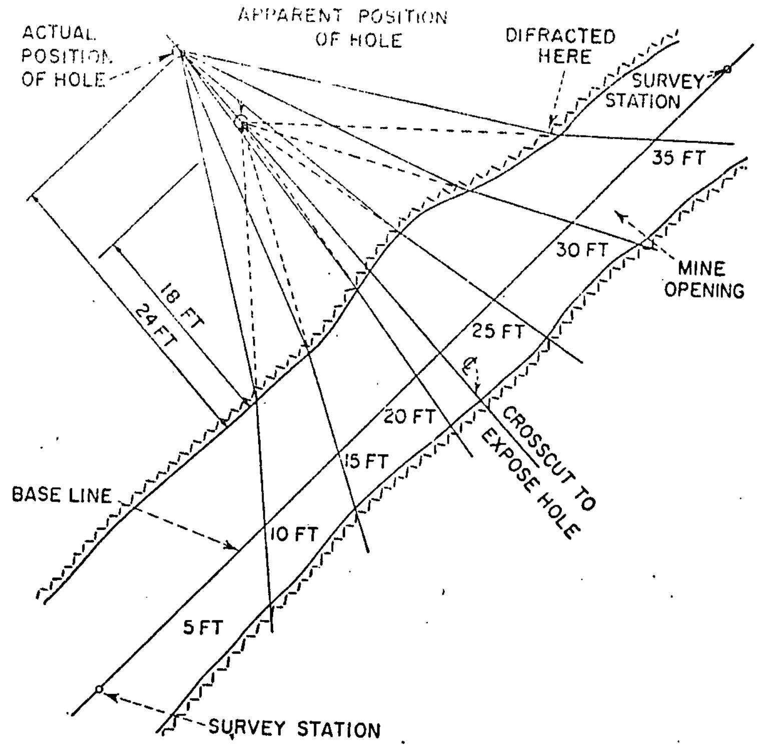

FIG. 2. DUE TO DIFFRACTION OF RADIO WAVES in rock and air, position of the hole will be outside plotted position, but in same plane.

How Radio Locates Drill Holes Underground

ROBERT P. CORBETT
Mining Engineer
Kelley mine, The Anaconda Co.,
Butte, Montana

APPLICATION OF THE RADIO DIRECTION FINDER PRINCIPLE has eliminated probe drilling, sounding and the use of deep-colored dyes in water-filled holes as a means of locating deviated drill holes. This rapid, reasonably precise and cost-cutting method is finding lost diamond and churn drill bottoms at Kelley mine, Butte, Montana.

Diamond drill holes for drainage are usually drilled from one accessible drainage working to another. Churn drill holes from the surface are drilled to accessible workings underground; serving the two-fold purpose of prospecting and opening-up for later introduction of air, concrete liners or electrical cables.

Both types of drills require careful and accurate setting for a successful holing to the target opening. Even with careful setting a drill may deviate. One way or another the deviated hole must be located. Once the location is known the hole can be exposed by removing ground in the proper place with a minimum of expense and delay.

First Try

It was the failure of such a hole to connect in the Kelley mine that led to the conception, construction, trial and success of the radio direction finder method for locating deviated hole bottoms.

As part of the Kelley drainage system, two parallel NX diamond drill holes were drilled from the 600 level to a small crosscut south from the end of the main shaft on the 1100 level. Vertical distance was 455 ft. The first of these two holes was drilled and holed to the target with a surveyed deviation of only two feet.

Unfortunately, the degree and direction of deviation of one hole may have little or no bearing on another drilled adjacent or in similar ground. The second hole, which was offset two feet from the first and on same dip and strike, did not hole target after drilling to proper depth. The usual test holes, soundings and dye tests gave no clue as to the whereabouts of the hole on the 1100 horizon. It was at this point that radio direction finder method was conceived and tried. Bureau of Mines test at Mammoth Cave in 1929 gave us the basic information.

Assisted by the mining engineering department of Anaconda Co., we tried the following method: A radio signal was introduced into the bottom of the drill hole and bearings taken on the source of the signal at the target level horizon by means of a radio direction finder. Bearings were plotted on a simple sketch and the point of intersection of the bearings gave the point of origin of the signal; and the location of the drill hole.

On the basis of this information, ground was removed at the point indicated and the bottom of the hole exposed. Hole had deviated about 15 ft into the crosscut wall.

Since this first trial, more than a dozen holes have been successfully located in drift and crosscut walls. Deviations from 8 in. to 24 ft have been located. In several instances crosscuts were driven to intersect holes at intermediate horizons simply by following the directions as indicated by the rotating loop antenna on the receiver.

September, 1955

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Transmitter Is Small

Transmitter used at Butte is a single tube, self-excited oscillator employing electron coupling. Comparatively low frequency signal is used. Tuning circuits of the transmitter operate on any frequency from 200 to 500 kc. This frequency was chosen since it required only minor modification of readily available equipment.

Transmitter, small, self contained and weighing only a few pounds, is powered by 6 volt battery or four No. 6 dry cells in series. Vibrator supply furnishes plate voltage. About 250 volt dc is required. Output of vibrator supply is unfiltered so that the 180 cycle frequency of the vibrator modulates the radio signal at the same frequency, making it audible and easy to identify.

Effective power of the transmitter is 3 or 4 watts. Radio frequency energy generated is capacity-coupled to a wire, one end of which is lowered to the bottom of the drill hole. Wire serves as antenna and introduces the signal into the target area. Single conductor rubber-covered telephone wire has been used as antenna and has been lowered into holes 800 ft deep. Insulated wire is required to prevent leakage of signal to ground, since most of the holes are damp or water-filled.

Receiver is battery-operated broadcast set with some minor modifications. Modifications include the shielding of the entire receiver in an aluminum cabinet, extending the tuning range to include those used in the transmitter, the addition of a rotary loop antenna and earphones to exclude noises commonly encountered underground. Loop, about 10 in. in diameter, is shielded and balanced to ground in order to eliminate anti-Marconi effect, which would impair the directing characteristics of the antenna.

Method

In practice the antenna wire is lowered to the bottom of the drill hole. Transmitter is then coupled and turned on. Once in operation no further attention is required during the survey. At the target area the signal is tuned-in on the receiver and a short base line is established.

Base line is usually established with reference to a mine survey station or is actually connected between two stations when possible. At points along the base line the directing loop of the receiver is rotated to determine the bearing of the signal coming from the antenna in the drill hole. Rotation of the loop through 360 degrees gives two points of maximum response and two null points. Null points, sharper than maximum position, are used to plot bearing.

Since the loop gives the bearing of the signal and not the direction from which the signal is coming several bearings are taken along the base line to fix the signal. Common intersection of all bearings indicates hole.

From the point of common intersection a perpendicular is drawn to the base line so that the distance from the base survey point to a point directly opposite the hole can be determined. It is along this line that excavation is made to the drill hole.

Equipment and method have proven valuable and yield considerable savings in recovery of deviated holes. Results have been successful in the Butte district granite and in the limestone and chert in the Conda, Idaho, operations of the Anaconda Co. A minimum amount of interpretation of data or calculation is required after the survey is completed. Holes were drilled into the crosscut walls and intersected the deviated hole at the position indicated by the survey.

Range Is Definite

Water-filled holes or those in the vicinity of metal-bearing veins or faults present no problem. Experiments conducted to date show a practical and definite range for the method owing to the high degree of absorption of the radio energy by the rock.

Amount of absorption depends on rock conductivity, permeability, dielectric constant and the frequency of the signal. Maximum range of the equipment and frequency used here at Kelley is about 40 ft. Waves of much lower frequency would undoubtedly yield better results.

Owing to the difference in velocity of radio waves in ground and in air, some degree of diffraction of the signal occurs at the disconformity or crosscut walls. Because of the nature of the medium through which the wave travels other diffractions and reflections are probably present. Holes appear to be closer to the mine face than is actually the case. (Fig. 2.)

This is academic, since the direction line to be followed to expose the hole is of primary importance. This line is normal to the base and indicates the shortest distance to the hole.

Inasmuch as an antenna wire is needed in the hole, drilling rods or tools must be removed from the hole. The method is limited to down holes or holes with sufficient dip to allow the wire to be lowered to the bottom.

In both churn and diamond drill holes cased with steel pipe this method will work, provided a short distance is left uncased at the bottom. Signal will not pass through pipe effectively.

More Data on EDTA Analysis of Cu-Pb-Zn

IN APRIL WE PUBLISHED an article by Jorma Kinnunen and Bertil Wennerstrand covering the rapid analysis of Cu-Pb-Zn and others. In response to the many requests for further information Mr. Kinnunen offers the following data on reagents and procedure. A bibliography of literature covering this method of analysis is available from *E&MJ* to those interested.

EDTA can be prepared by dissolving 18.605 grams disodium ethylene-diamine tetra-acetate in one liter distilled water (0.05 N).

Buffer solution is prepared by dissolving 350 ml concentrate ammonium hydroxide and 54 grams ammonium chloride in one liter distilled water.

Manganese salt of EDTA is prepared by dissolving 0.02 mol manganese sulphate, 0.02 mol disodium ethylenediamine tetra-acetate and 5 ml concentrate ammonium hydroxide in one liter water.

Dilute 25 ml of this solution to 200 ml and add 20 ml buffer solution. Add 0.1 gram ascorbic acid. Titrate against Erio T with either 0.01 N EDTA or 0.01 N manganese sulphate.

Correct the main portion (975 ml) of this solution by adding equivalent amount of EDTA or manganese sulphate, depending upon the results obtained in the test titration. Add sufficient amount of the correct reagent to give stoichiometric solution of manganese salt of EDTA.

Iron determination is generally made on separate sample and step three is omitted from the procedure for Cu-Pb-Zn.

Step No. 4 has been altered as follows: After titrating copper add 20-30 ml triethanoline (1:1) and rapidly add 10-15 ml KCN and 10 ml concentrated ammonium hydroxide. Dilute to 300 ml with boiling water. Add ascorbic acid until nearly colorless. Add 5-10 grams ammonium fluoride; cool and titrate Pb-Mn against Erio T with 0.01 or 0.05 N EDTA. Toward the end of the titration add 5-10 ml manganese salt or EDTA for better end point. Use electric light behind beaker for better visual end point control.

Alternate method to the above is to add ascorbic acid, until nearly colorless, to the hot dilute solution after decomposition (step No. 1) and then titrate hot for Pb-Mn-Ca-Mg with Erio T and EDTA. Cool and titrate Zn as in step No. 5.

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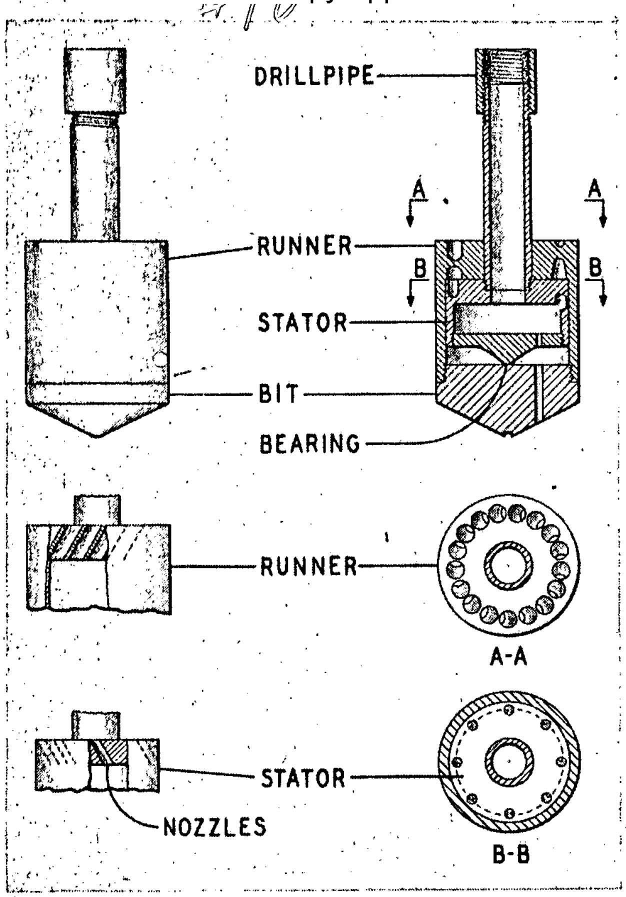

FIGURE 1—This is the basic concept of the primary element of the turbo drill as designed by Dr. C. G. Cross in 1873.

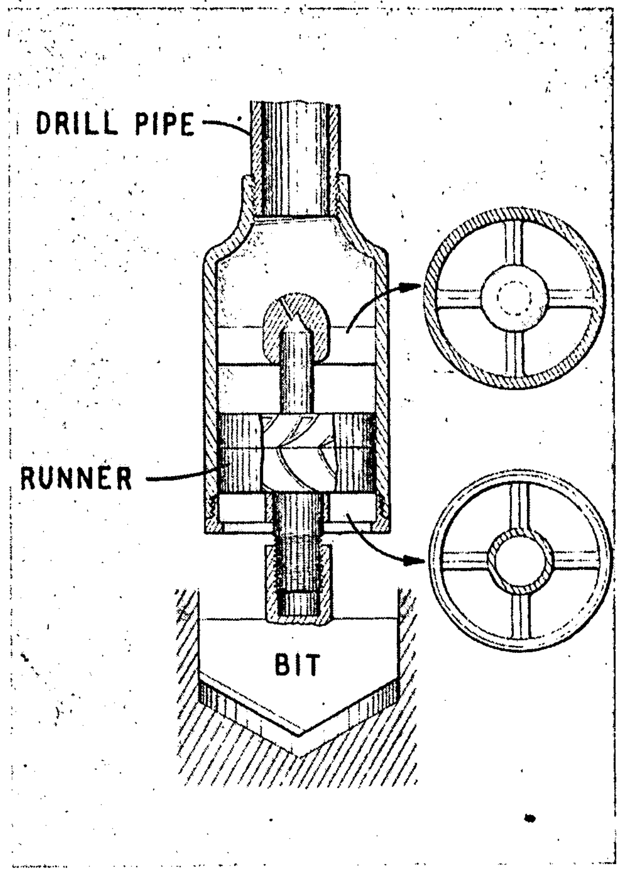

FIGURE 2—This is an improvement of the Cross turbo drill design as undertaken by M. C. Baker in 1884.

Special Turbodrill Report

Turbodrill Development—Past and Present

A roundup of turbodrill developments from 1873 to the present with reported results compared with modern rotary methods.

By J. H. THACHER, California Research Corporation
and
W. R. POSTLEWAITE, The Standard Oil Company of California

Although much of the performance data on turbodrills are based on official reports from Russia, a recent and comprehensive French engineer's appraisal shows that basically the new heavy duty turbodrills have ample power to exceed the performance of the rotary in medium or hard rock drilling. The mechanical developments leading up to the present day turbodrill are noted and the steps needed to demonstrate the economic possibilities of the new tool in the U. S. are outlined.

The increasing difficulty in finding large new sources of domestic petroleum and the higher cost per barrel of such oil, are further pressures compelling a critical review of our present methods of drilling and to consider their improvement.

Drilling Research. Speaking from a research viewpoint; to reduce drilling costs materially we must continue not only to improve present methods, but to seek new and better methods of penetrating and removing rock. Much further research is needed to extend our knowledge of the basic physics and mechanics of drilling. More should be understood about the process of rock failure beneath the bit, and what physical properties of the rock are most important in this process. The effect of overburden pressure and the mud column pressure on the bit's ability to penetrate should be known. The stress distribution in the rock at the cutting face, and the effect of this stress distribution on chip formation should also be understood.

In short, while we have learned something about the basic principles important in drilling through rock, much remains to be known. The end result of this search might well be an entirely new process of rock penetration. By "new" is meant something like drilling with the energy of sound, or with thermal energy, or with any type of energy used in a manner quite

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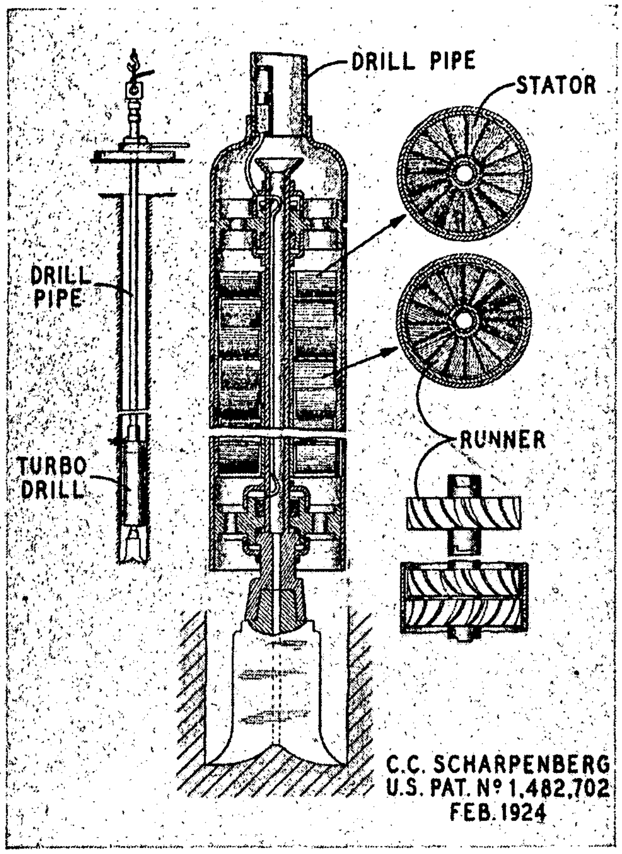

FIGURE 3—This simple, multi-stage, axial flow, turbodrill was developed by C. C. Scharpenberg of Standard Oil Company of California and patented in 1924.

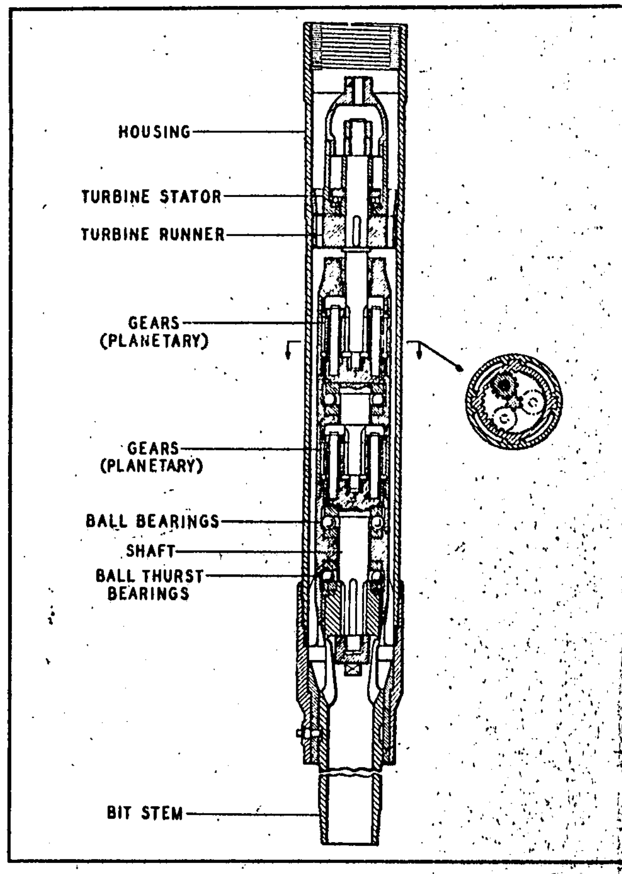

FIGURE 4—Early Russian, single-stage, high speed mud turbine, patented September 15, 1924.

different from our present direct application of mechanical energy.

An entirely new process could take many years to develop. In the meantime, there are several different schemes of applying mechanical energy to the bottom of the hole that are more apt to result earlier in a tool better suited to our field use. Three of these are currently undergoing extensive research and development; the first two are new percussion tools, and the other is the turbodrill. It is pertinent to note that all of these place the power unit at the bottom of the hole.

1. Magnetostrictive drill by Drilling Research, Inc. The drill operates from alternating electric current in a manner basically different from the usual electric motor or solenoid. Aside from this unique motor, the main point of the DRI method is that the bit can be made to strike the rock at several hundred cycles per second.

2. Sonic drill by Borg Warner. This, like the DRI drill, is a vibratory percussion drill. The power is transmitted to the 150 to 200 hp downhole turbo motor by the mud stream, rather than by electricity, and the frequency of mechanical vibration is much less.

3. Turbodrill. The turbodrill, which is in a more advanced state of development, will be discussed.

What is the Turbodrill? If the conventional rotary drill is considered to be approaching the limit of its possibilities, as some informed people have reason to think, the present day turbodrill may now be described as the promising economic substitute for the rotary, particularly when drilling in rock below 6000 to 7000 feet. On this basis, the turbodrill is evidently on the threshold of widespread use in the medium and hard rock formations where it is most applicable and effective. The turbodrill may be defined as a drilling process which has the important characteristic of maintaining its power available at the bit regardless of the hole depth. This is not true of the rotary which rapidly loses much of its power due to friction of the rotating pipe in the hole that, at depths below about 6000 feet, it has sacrificed most of the table's input in drag on the mud and on the hole wall. At 10,000 feet, it has inadequate power and speed at the bit to satisfy optimum drilling conditions. Quoting from a French article—"It is decidedly an impasse where such a relatively small tool (weighing about 200 pounds) is turned too slowly in a system that must expend as much as 90 percent of the power applied to merely rotate a 'tool holder' weighing over a hundred tons."

The modern turbodrill has few basic parts. These include an external cylindrical and nonrotating body, a central shaft that is guided by rubber thrust and radial bearings, and which carries the bit mounted directly on the bottom end, and finally the 80 to 100 turbine stages. Each of the stages is composed of a fixed stator solidly mounted in the main body and having blades which direct the fluid toward similar curved blades of the rotor element mounted on the shaft. The mud, in flowing rapidly downward through the turbine blading, imparts reaction torques on the blades of each runner to drive the unit. The mud also lubricates and cools the various bearings. The cumulative effect of the torque reaction from all the stages of the mud tu-

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then develop the power to drive the bit. Unlike previous experimental turbos, the new models have an abundance of power and torque, and are reported to have practical durability. The horsepower now ranges from 300 or 450 hp, bit speeds are from 500 to 900 rpm with bit loads of 20 to 35 tons, and the running torques are on the order of 2000 to 3000 lb.-ft. This is enough to turn effectively almost any bit.

The Important Beginning. The earliest record of any liquid-powered turbodrill for boring wells credits Dr. C. G. Cross of Chicago, who in 1873 disclosed the basic concept of the primary element of the turbodrill in his U. S. Patent 142,992. His design is shown in Figure 1. It was this single-stage type of turbine, with its very high nozzle velocity, that was used 51 years later by the Russians in their first turbo design in 1924.

In 1884, M. C. Baker, in the territory of Dakota, undertook to improve on the Cross turbodrill, and the design illustrated in Figure 2 was then shown in a U. S. patent. It is interesting to note that the advantages originally cited by both these early U. S. pioneers are still valid. Mr. Cross correctly pointed out the serious limitations on the drilling depths of the rotary (diamond drill) of that time, and the reason for proposing the new bottom hole turbodrill principle. His patent explains that although the rotary diamond drills of that period had been used with considerable success to a depth of 300 feet, the tube to which the bit was connected,—"was liable, because of the great strain upon it and its great length, to become bent, twisted, and broken." He further states:

> "The object of my invention is to drive the drill at the bottom of the well without turning the rod or tube with which the drill head is connected, thus obviating the difficulty mentioned, and rendering it practicable to drive a drill at the bottom of a well of great depth."

Thus, the fundamental use of the turbodrill for deeper drilling, and the inherent and still real advantage over the rotary, was clearly established 83 years ago.

In 1901, with the advent of the rotary well drilling method at Spindletop near Beaumont, Texas, the rotary drill, together with the percussion cable tool system already widely in use, became the two generally accepted drilling processes. They were the proper economic choice (particularly the rotary) for about the next 50 years because the drilling depths were on the average fairly well suited to the effective working ranges of that equipment.

However, as early as 1922, C. C. Scharpenberg, then chief engineer of the Producing department of Standard Oil Company of California, had the foresight to visualize the possibilities of a turbodrill for the well depths of the future. Furthermore, the limitations of the rotary for deep drilling were already starting to appear. In October of that year he applied for a patent on a simple multi-stage axial flow turbodrill constructed as shown in Figure 3. His patent was issued on February 5, 1924, and the first test drilling was done in 1926 in Elk Hills, Calif. On Sept. 15, 1924, seven months after the Scharpenberg patent was issued, Russian Patent No. 546 was allowed to M. A. Kapelyushnikov, who conceived of a quite different approach to the problem for driving the bit at the bottom end of a stationary drill pipe.

This early Russian turbodrill design employed a single-stage high speed (1800 to 2000 rpm) mud turbine, with a nozzle mud velocity of about 200 fps, and a mud flow rate of 200 to 300 gpm. This turbine was geared down through one to three stages of complex planetary type gearing, running in oil and enclosed in a sealed box to give the low bit speed of 50 to 100 rpm then used in rotary drilling practice. This turbodrill design shown in Figure 4, was of lower power, delivering but 12 to 15 hp at the bit. It is reported to have been used first in Russia in 1925.

By 1930 the usable service run was still limited to but three to four hours on bottom, due to loss of lubricant through the shaft seals which the mud cut out, thus resulting in bearing failures. Scharpenberg's early sealed shaft bearings suffered similar packing failures, but the low mud velocity which has characterized his lower speed turbine gave no erosion problem, whereas the 200 feet per second jet velocity of the Russian design resulted in excessive turbine wear.

Scharpenberg Models. In 1935 the Scharpenberg turbo shaft was fitted with the first rubber radial guide bearings, and the ball thrust bearings at the bottom end were re-designed by the A. C. Smith Corporation and boldly opened up to run directly in the bud without seals; see Figure 5. This model retained the original simple and basic multi-stage turbine arrangement, with the bladed runners mounted directly on the long shaft carrying the rotary bit. The horsepower for a 30-stage, 9-inch size unit was about 92 at the rated speed of 700 rpm, with a flow rate of 550 gpm, and a turbo pressure drop of 580 psi. The maximum fluid velocity then used did not exceed about 20 feet per second, so the mud abrasion was minimized.

Five wells were drilled for the Producing department of Standard of California with this experimental equipment by 1941 when the war interrupted the work. In 1950 testing was resumed with the same 9⅝-inch turbo drilling to 3000 feet near Coalinga, Calif. The average penetrating rate was 51 feet per hour, using 4000 to 5000 lb bit load, 5½-inch drill pipe, desanded mud, and bit speeds up to 1200 rpm. However, with the rotary improvements made during the war years, the rotary drilled holes in the immediate vicinity had higher average penetrating rates and, although this turbo developed over 200 hp in this last test, it was concluded that a heavier duty unit was required using multi-step rubber thrust bearings which had been designed earlier in 1945. This design is shown in Figure 6.

The EDCO Drill. Another American turbodrill, developed in 1945 to 1950 by the Engineering Development Company in the Mid-Continent, is shown in Figure 7. This design resembles some of the previous constructions and also employed sealed ball thrust bearings. With 90 turbine stages and a speed of 400 to 500 rpm, this unit was rated at 310 hp, but in five test wells serious wear was experienced with the running parts and the available mud flow rate was not always sufficient. The penetrating rates were about the same as for the conventional rotary rigs in the area.

Russian Designs. During the 10 years prior to 1934 the Russians had experienced very limited success with their turbodrill, even in their shallow drilling. In 1930 the early model Russian turbodrill was tested in the Mid-Continent for The Texas Company and the Magnolia Petroleum Com-

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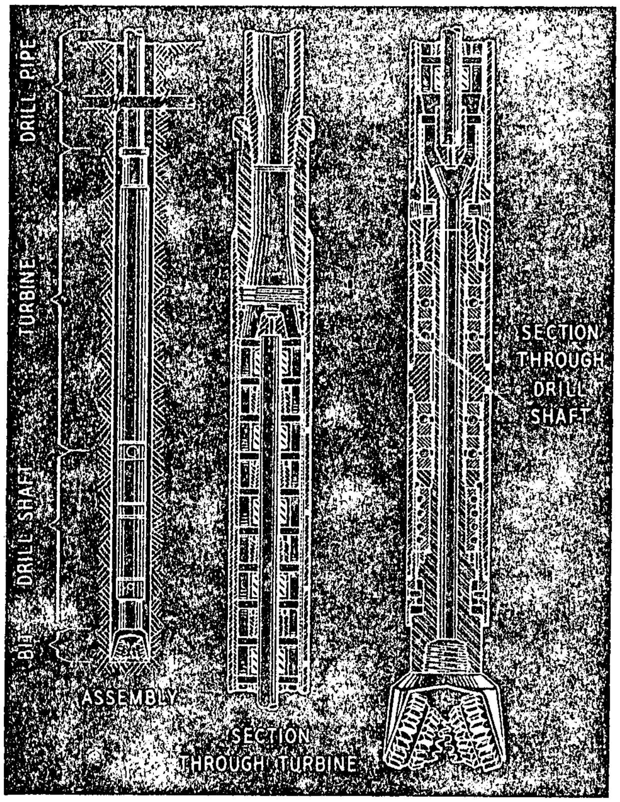

FIGURE 5—The Scharpenberg turbo shaft was fitted with the first rubber radial guide bearings and A. O. Smith Corporation redesigned the ball thrust bearings so that they ran directly in the mud.

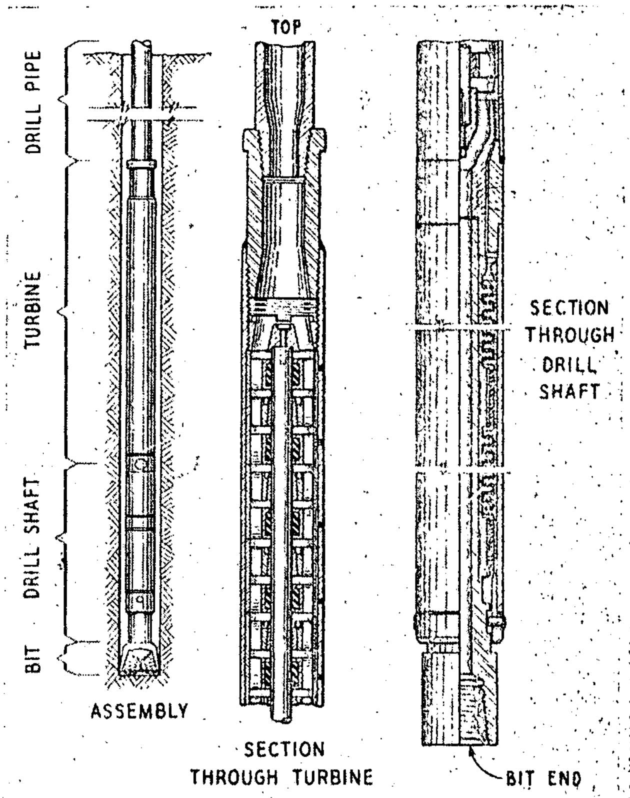

FIGURE 6—The Standard Oil Company of California turbodrill of 1945 with multi-step rubber thrust bearings.

pany. The general lack of success was due in part to their complex turbine gearing which was so difficult to seal off from the drilling fluid. In 1935 they abandoned the single stage, high speed turbine and its sealed gears, and resorted to Scharpenberg's much simpler general arrangement of a multi-stage, axial flow, design with the bit mounted right on the bottom end of the turbine runner shaft. This multi-stage design offers a fundamental advantage since it makes it possible to increase the total pressure drop while retaining a relatively low pressure across each turbine stage. In consequence the life of the turbine has been extended to an acceptable value which now makes possible the economic exploitation of the turbodrill. By 1940 the Russian multi-stage turbodrill looked like Figure 8, in which they still clung to the ball thrust bearings sealed by a stuffing box which persisted in giving unsatisfactory results. The ball thrust bearings lasted but 8 to 10 hours in service, just about as we had previously experienced.

By 1945 their TM14-9¾-inch turbodrill with 96 stages, developed 100 hp, and in 1948 a radical change in bearing design was made. Sliding rubber thrust bearings were substituted for the steel ball bearings. This permitted designing much heavier duty units. In 1950 their present 10-inch turbodrill was evolved. This unit develops up to 450 hp at a bit speed of 790 rpm, with 1030 gpm of mud at 1090 psi, and a torque of about 3000 pound foot. This over-all design is now as shown in Figure 9, and except for the important difference in the thrust bearings, it is remarkably like Scharpenberg's earlier turbodrill of Figure 6. This Russian tool, with its mud jet velocity now reduced to 20 to 30 fps, and with the turbine elements constructed similar to the French design shown in Figure 10, is evidently a practical drilling unit which has been widely used for depths to 13,000 feet and deeper. The deepest turbo drilled hole reported to date in Russia is 16,400 feet.

The French Drill. Recently, after two years of design work, the French company, Establissement Neyrpic, in Grenoble, France, has designed a turbodrill based essentially on the latest Russian developments. This firm has built and tested two 10-inch diameter units. (This size develops about 300 hp at 600 to 800 rpm). They have arranged for manufacture of their turbodrill in Germany. Dresser Industries in the U. S., after completing an arrangement with Neyrpic, are undertaking to test and exploit the tools on this continent. Forty Russian turbodrill assemblies have now been imported, and delivery of a quantity of the Neyrpic units is pending.

This brings us up from Christopher Cross in 1873, to the present heavy-duty turbodrill which now, with millions of feet of hole behind it, is said to account for over 80 percent of the current Russian drilling program.

Thrust Bearings. A vital feature that has contributed greatly to the successful development of a practical turbodrill is the mud-lubricated, multi-disk, rubber thrust bearing as finally perfected by the Russians and illustrated in Figures 6 and 9.

The only practical thrust bearing capable of satisfactorily coping with the turbine's unbalanced hydraulic downward thrust of 30 or more tons, or the upward bit loads of similar magnitude, at shaft speeds of 500 to 900 rpm, is the resilient rubber thrust bearing which cushions the pump

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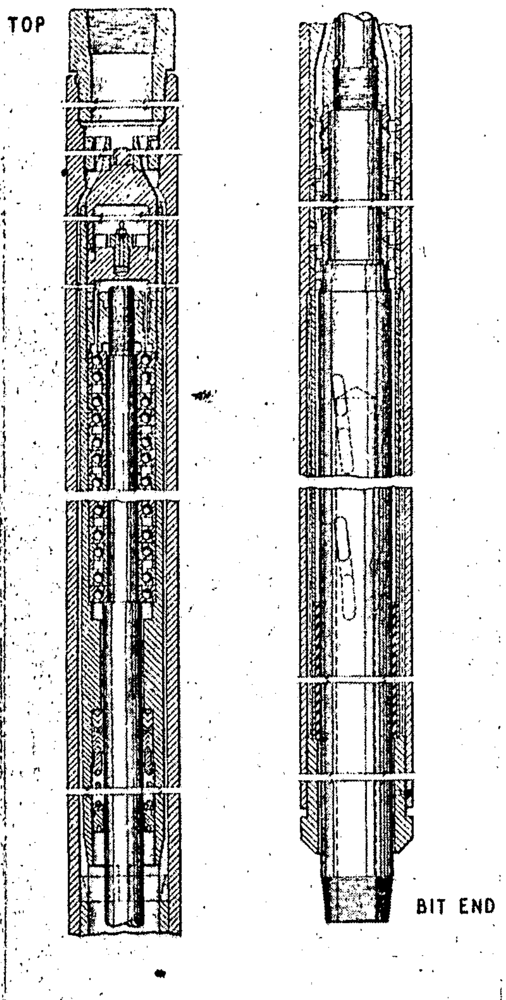

FIGURE 7—This turbodrill designed by the Engineering Development Company between 1945 and 1950 resembled previous designs and employed the sealed ball thrust bearings.

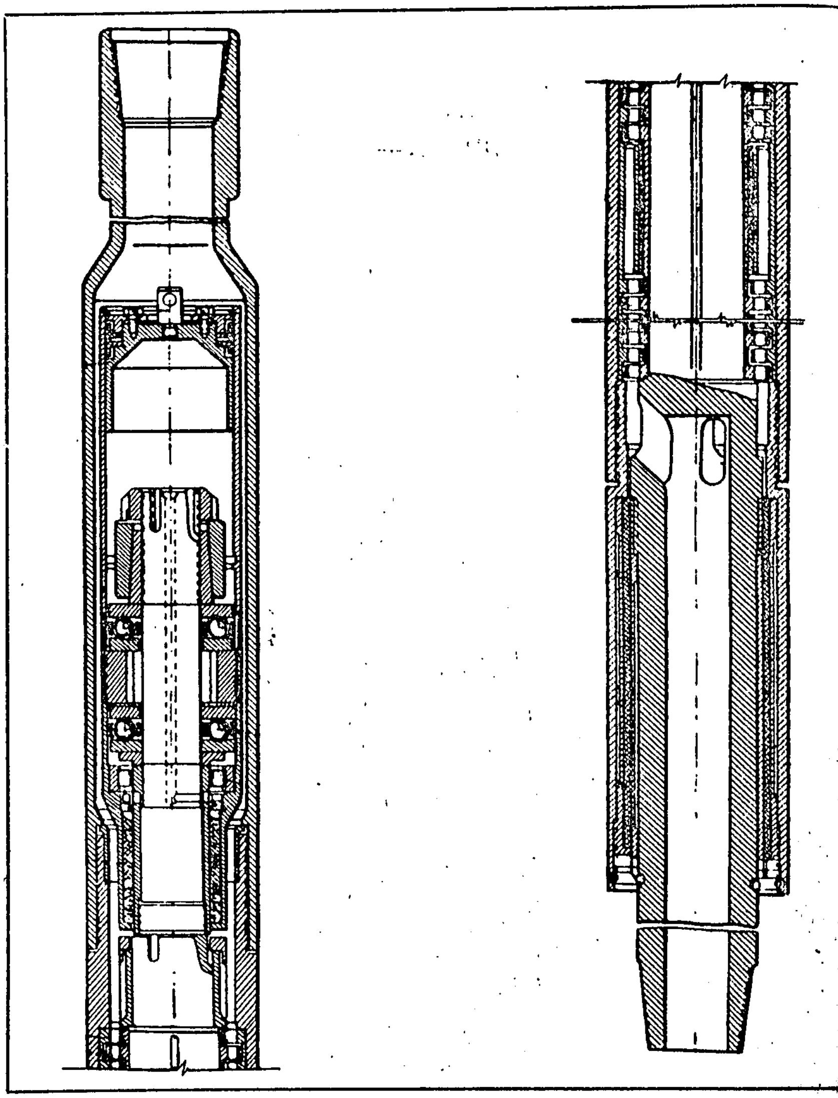

FIGURE 8—This is a cross-section of the Russian turbodrill of 1940. Note the continued use of the sealed ball thrust bearings.

pulsations and the bit reactions. These bearings, with 10 or more disks in series, and unit bearing pressures of over 150 psi, are reported to be remarkably durable with a service life of about 100 to 150 hours. This is primarily due to the elasticity of the rubber. Abrasive particles in the mud simply deform or press into the rubber and roll or are washed out, without injuring it.

However, a certain penalty which may accompany this simple and practical bearing arrangement is its frictional power loss. With clay mud, the bearing friction coefficient is about 0.075. A 9¾-inch turbo, if run with a difference of 10 tons between the downward hydraulic thrust and upward bit load, at a shaft speed of 700 rpm, would incur a significant bearing power loss of about 40 hp. The mud, must obviously cool as well as lubricate this type of bearing. Operating the turbo with water instead of drilling mud reduces the bearing friction by 50 percent, and so releases considerable additional turbine power to be applied to the bit. This materially reduces both turbine and pump maintenance, and also improves the drill's penetrating rate since there is more power for the bit.

The present rubber thrust bearings are reported to be virtually trouble free, particularly when run on water. When worn out, the bearing stack is removed as a unit and replaced. Where the formation permits, maintaining the bit load as close as possible to the heavy downward hydraulic turbo thrust, would balance out or unload the thrust bearings. This is not always practical or desirable from a drilling standpoint. Standard of California has several designs for balancing 50 to 60 percent of the turbo hydraulic thrust, and it is believed that this device will materially reduce bearing wear, and have use in future turbo drilling.

Why The Turbodrill. As analyzed by W. Tiraspolsky and his co-authors in the copyrighted French publication, "Revue De L'Institut Francais Du Petrole," for August, 1955, the rotary drilling system, supplanted the cable tool system only because the rotary succeeded in transmitting more power to the bit. The results of his analysis as treated below, shows that a 12-inch diameter 3300-pound cable tool, running at 50 blows per minute, would require the equivalent of about 2[illegible] horsepower.

The rotary, on the other hand, may transmit to the 12-inch bit the following horsepower values; (these are

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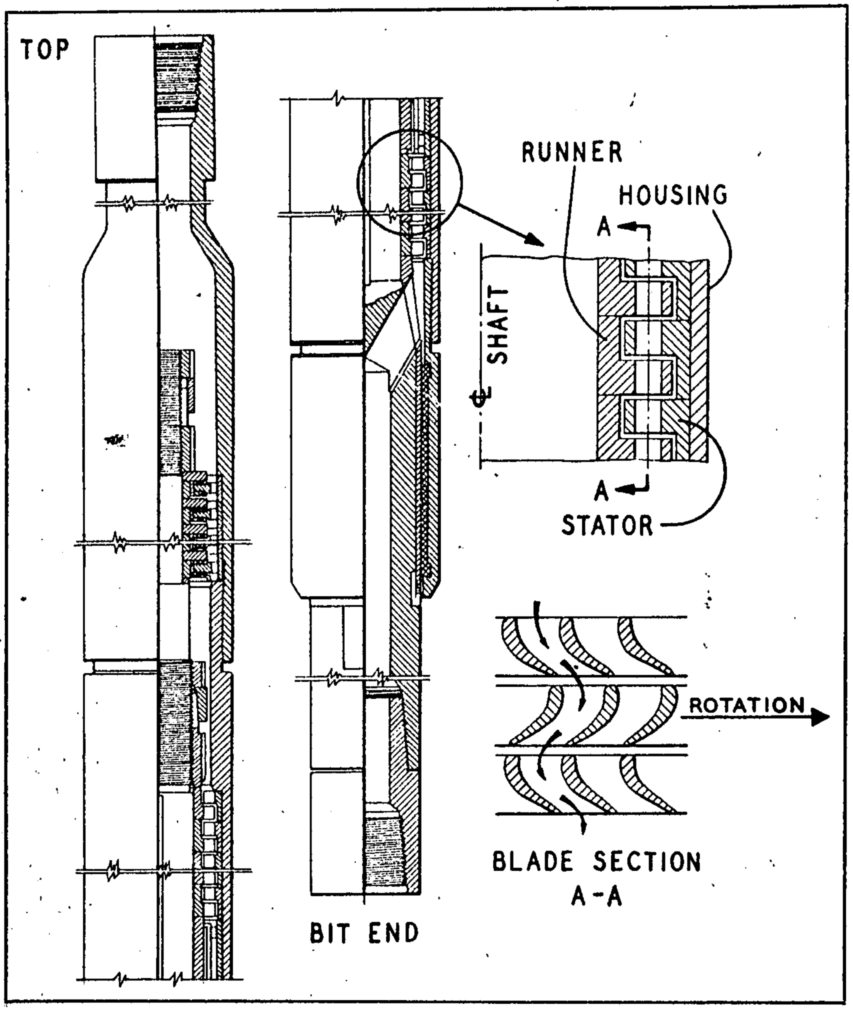
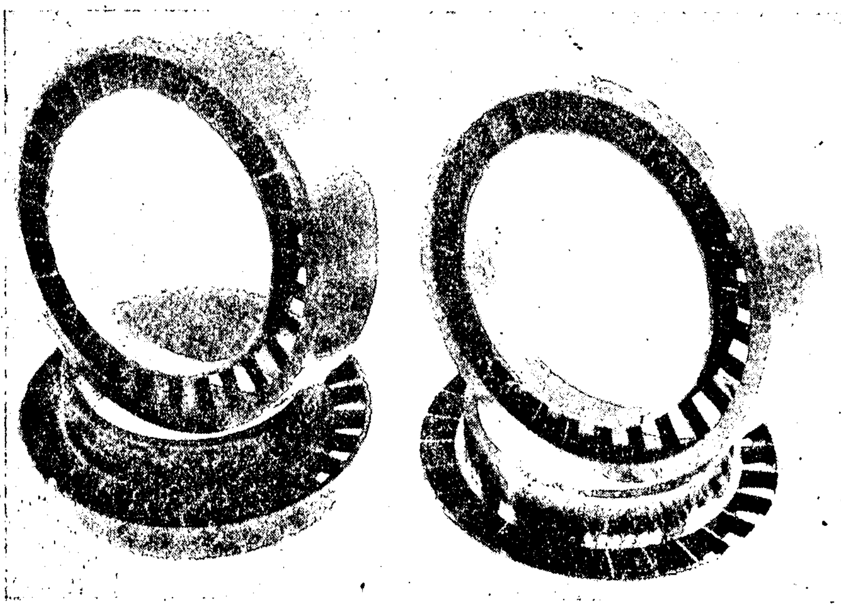


FIGURE 9—The Russian turbodrill T14—9¾-inch is remarkably like the Scharpenberg design except for the sliding rubber thrust bearing.



Courtesy 1955 Institut Francais du Petrole and J. B. Bailiere et Fils, Paris

FIGURE 10—Turbine elements, stator and rotor of the French turbo. The Russian elements are very similar to these.

given as maximums rarely exceeded in practice):

Depth Range—Ft.	HP Available at Bit
0 to 3300	40 to 70
3300 to 6600	30 to 50
6600 to 10,000	20 to 40

The rotary is seen to have about twice the bottom hole power of the cable tool. This difference resulted in a real but modest increase in penetration rate. The rotary also extended the effective working depth well beyond the normal 5000-ft. economic limit of the cable tool. However, the diminishing amount of power available at the bottom of the rotary string leaves much to be desired as the hole deepens, and now the turbodrill offers an effective answer to modern requirements as shown in the following comparison:

	Available HP at 12-in. Diam. Bit
12-inch Cable Tool	26
12-inch Rotary (max. conditions)	70
10-inch Turbodrill	190 to 285 (with 300 maximum)
8-inch Turbodrills connected in tandem	210 to 285 (with 380 maximum)

Thus, according to the French reference cited above, it is seen that turbodrills can deliver three to five times as much power to the bit as the best conditions allow with the rotary. Furthermore, under normal or average drilling conditions, the turbodrill bit attacks the formation with eight or more times the power of the rotary.

With the drill pipe and surface facilities currently in use abroad, about ¼ to ⅓ of the power input to the mud pumps is effectively delivered to the bit by the turbodrill. Thus with a 250 hp turbodrill, 750 to 1000 hp input to the mud pumps is required. The mechanical efficiency of the turbine alone is understood to be on the order of 65 percent for the new Neyrpic designs. The Russians report even higher values, i.e., up to 70 and even 80 percent, although in practice wear probably would reduce the effective value to nearer 60 percent.

The type of formation drilled, affects the relationships between the rotary and the turbo. It is not implied that the turbodrill is a complete cure-all for all drilling. It is primarily a hard rock drill. In many Gulf Coast areas, and some others, it may not equal or keep pace with certain rotary techniques now used with jet bits. Current turbo and rotary drill-

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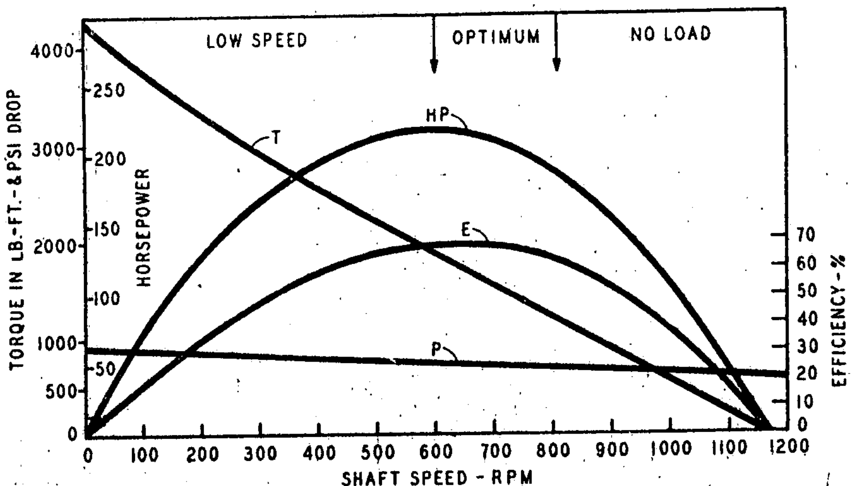


Courtesy 1955 Institut Francais du Pétrole and J. B. Baillière et Fils, Paris

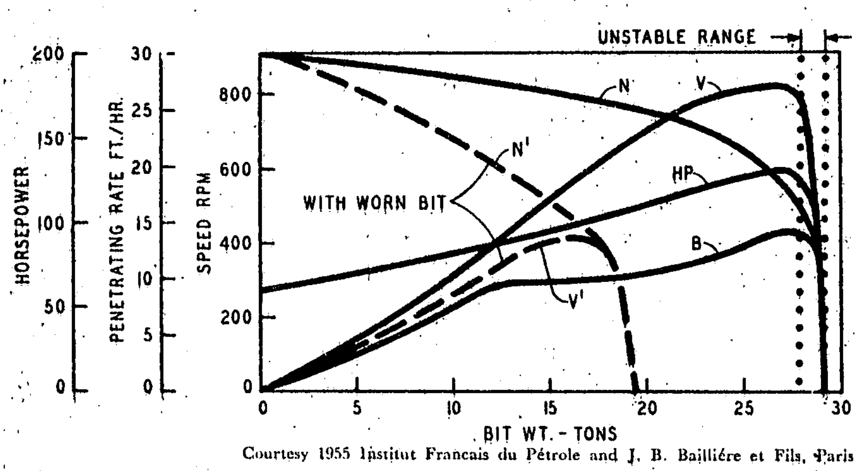
HP—Effective Delivered Horsepower at the shaft
T —Torque in Lb.-Ft.
P —Pressure Losses in the Turbine in PSI
E —Mechanical Efficiency —%

FIGURE 11—Characteristics of Russian 10-inch Turbodrill.

ing in soft formations in Holland also confirms this.

Turbo Drilling Bits. The next question is the problem of bits suited to the turbo's drilling conditions of weight and higher speed. To take proper advantage of the turbo's great bottom hole power, of course, requires that the bits be capable of withstanding the considerably higher running speed combined with the heavy loads that characterize the turbines currently available. Russian experience, as reported for a wide variety of formations, has repeatedly demonstrated that the footage drilled per bit exceeds that of their best rotary practice in the same areas. (A recent test hole in France with the Neyrpic drill gave a similar report.)

As a result of the improvements in the performance of the modern Russian turbodrills, the high rate of penetration now realized, has affected such a decided reduction in the net on-bottom drilling time, they now conclude that any likely further increase in the penetrating rate would not materially improve the over-all economics of turbodrilling. The hoisting and lowering operations constitute a large percentage of the time, and the important feature is to extend the bit life so as to increase the



Courtesy 1955 Institut Francais du Pétrole and J. B. Baillière et Fils, Paris

N —Speed of Rotation
HP—Developed Shaft Horsepower
B —Horsepower Used by Bit
V —Penetrating Rate Ft./Hr.
With New Bit

FIGURE 12—Experimental Characteristics with 10-inch Russian turbodrill as the bit loadings are progressively increased from peak penetrating rate, into the zone of speed instability, and finally into a complete stall.

ratio of the net drilling hours to th total elapsed time.

Our present day rotary bits, developed to suit the slower speed rotary drilling, may not allow the more powerful turbodrill to achieve its optimum performance in hard rock drilling. The French reference cited above, states the present situation substantially as follows:—In contrast to the definite influence exerted by the development of the tri-cone bit on the trend of the rotary design in past years, we now find the turbodrill imposing its characteristics on the tri-cone bit.

Tests by a major tool company on conventional rotary rock bits show that above a certain rpm the rate of penetration does not increase proportionably with rotary speed. Bit wear increased rapidly at high rpm. However, it is very important to appreciate that the new turbos have definitely moved the power bottleneck from the top of the long drill string right down to a point directly above the bit. This is an important advantage and we can take fullest advantage of this by producing bits that can stand up under the heavier duty now available with the modern turbo. Meanwhile, even present tri-cone bits on the turbo are evidently capable of showing improved performance over the rotary as the hole deepens. Oil field equipment manufacturers, in this country, as well as elsewhere, are now devoting particular attention to the new turbo bit problem. If the concerted effort of the bit suppliers is augmented by U. S. users who will obtain the necessary field experience here in drilling with the new turbodrills, a balanced bit design may be expected with the promising incentives involved. Extending the turbo drilling depth on beyond 20,000 ft should then be possible. Although the turbo does promise to be superior to the rotary, particularly at extreme depths, there are many formidable hazards inherent in such deep drilling which would not be altered by the use of the turbodrill.

Using the Turbodrill. There are several characteristics of the turbodrill that may be pointed out in connection with its proper application and performance.

As shown in Figure 11 the performance characteristics of a 10-inch Russian turbodrill indicate that maximum power and turbine efficien

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occur at a shaft speed of about 600 rpm, or half the no-load or idling speed of 1200 rpm. Observe that the torque drops to zero at the idling or no-load speed, and at the other extreme, with the turbine stalled, the torque is then twice the rated value developed at 600 rpm. This fixed maximum limit on the torque at stall is another pertinent advantage over the rotary, and is an automatic built-in protection against excessive overloading of the pipe in deep holes.

Since the maximum amount of power which the turbine can generate for the bit is dependent on a certain optimum range in shaft speed, which is between about 550 to 800 rpm, as noted at the top in Figure 11, and since this power can only be realized by properly adjusting the external braking action by suitably loading the bit, it is seen that the driller sorely needs to know the shaft speed so he can apply the proper weight on bottom. Audible sounds emanating from the bottom hole turbine and bit become meaningless with depths below a few thousand feet. The "blind" operating procedure used to date to keep the bit working, has been first to stall the bit by applying excess weight, and then to back off a few tons to allow drilling to proceed. Observing and using the bit weight which seems to give the highest penetrating rate, has evidently been the usual method, but this is a rough visual approximation which would not always be conducive to best or consistent results with the turbodrill.

The further test data in Figure 12 shows what is reported to happen with a 10-inch Russian turbodrill as the bit loading is progressively increased right up to the peak penetrating rate, beyond into a zone of speed instability, and finally to a complete stall. To get the most footage the driller, of course, should try to operate as close as possible to the critical point near the top of the penetrating rate curve. Since the pump pressure, as shown in Figure 11 will tell him virtually nothing in the turbo's working speed range, a speed indicator at the driller's stand would be a decided advantage which should permit adjusting the bit load to maintain the bottom hole conditions for optimum power consumption by the bit. An electric speed indicator for this purpose was described in the ASME Paper No. 55-Pet-16, entitled, "Progress of Turbo-drill Development in California," which was presented by Postlewaite at the ASME Petroleum Mechanical Engineering Conference in New Orleans in September, 1955. Although this device is still in the development stage, certain down-hole tests have demonstrated that this principle of transmitting speed signals promises to be workable. Extending the application of this instrument to automatically control the proper bit weight-speed relationship also now appears attractive.

What It Means to You. The turbodrill, if properly applied, appears to be the most significant improvement in the method of drilling since the rotary was introduced in 1901. The reduction in unit drilling cost that is promised by the new turbodrills, based on information available in various credible published reports, may soon be demonstrated in this country. The aspects bearing on the effective use of this equipment, and which have been noted in the references cited at the end of this paper, are summarized as follows:

a. The penetration rate in rock is faster.
b. Better utilization of bits is possible.
c. More effective utilization of the drilling crews.
d. The drill pipe and tool joints should be lighter and probably cheaper.
e. With suitable heavy drill collars between the turbine and the bit hole deviation has been controlled.
f. Directional drilling is possible with the turbodrill.
g. Longer pipe life.
h. Fewer twist-off fishing jobs with non-rotating drill pipe.
i. The operations on the surface are relatively quiet with the turbo since the rotary table noise is virtually eliminated.
j. Swivel and rotary table maintenance should be minimized since the pipe is only turned occasionally.
k. Several turbos can be coupled together in series to permit a reduction in flowrate and bit speed as the hole deepens.
l. The hole gage is maintained more accurately with the turbodrill.
m. In foreign practice rubber protectors have not been required on the non-rotating drill pipe.

What Is Required for Turbodrilling. To realize the above, there are certain requirements to be met in outfitting and running a rig to operate effectively with 8-inch or 10-inch diameter turbodrills. These are enumerated below.

1. A minimum of three turbodrills are required per rig to permit turbo maintenance and continuity of drilling.
2. Provision of adequate pumping facilities to deliver about 800 to 1000 gpm, and at sufficient pressure to satisfy the 600 to 1000 psi additional pressure drop across the turbine.
3. Effective pulsation dampeners should be used. This smooths out the hydraulic loading on the turbo's thrust bearing, as well as the operation of the bit.
4. The drill pipe should be of a larger diameter than is normally used. The tool joints should be designed for a large bore to cut down flow resistance. The kelly should be at least 6 inch with a large bore, and the passageways through the bit should be enlarged to accommodate the increased mud flow.
5. The mud should be desanded to minimize wear on both the turbine and the mud pumps. The sand content should not exceed 5 percent, and 1 to 2 percent will probably be found more economical.
6. Means should be provided to indicate the turbine speed to the driller.
7. Personnel experienced in the proper use and maintenance of the turbodrill is most essential for the successful utilization of this new tool in our drilling.

ACKNOWLEDGMENT

The authors wishes to acknowledge assistance from Dresser Industries, Inc., Byron Jackson Division of Borg Warner, Hughes Tool Company and the National Supply Company. They are also grateful to The Carter Oil Company which released certain information on current turbo test drilling in Holland.

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#11

The Russian Claim . . .

Increased Drilling Rates With Turbodrills

A German scientist reports on the development of Russian drilling techniques.

By DR. ING. W. GRONEMEYER
Clausthal, Germany

DRILLING WITH turbines, as claimed by the Russians, is one way of improving the drilling technique. This method has been strongly developed in Russia during the past years.

This report is on the development of drilling techniques with turbines and the present day status of this drilling method in Russia as far as obtainable information permits.

Table 1 shows how quickly the development advanced in Russia between the years 1948 and 1953 and what percentage of the drilling was done by turbines.

TABLE 1
Percent of Total Wells Drilled By Turbodrilling Method

Year	Percent
1948	31.1
1949	44.4
1950	48.6
1951	57.1
1952	61.1
1953	75.8
1954	. . .

A turbine with vertical axis is mounted to the lower end of a stationary drill stem. High-pressure pumps force the drilling fluid through the stem into the turbine situated immediately above the bit and put the turbine shaft into rotation. The bit is screwed to the shaft of the turbine. The turbine and the bit make approximately 500 to 600 revolutions per minute. Like the rotary method, the mud flows to the surface between the drill stem and the well bore. By regulating the pump pressure it is possible to adjust the speed of the bit to the respective rock formations.

The drill stem does not rotate inside the hole; it merely serves to pipe the fluid into the turbine. The entire drilling process takes place at the bottom of the hole.

The turbine, a T 12 M 10" model, shown in Figure 1 has a diameter of 10 inches, a length of 28 feet and weighs 5260 pounds. The designation T-12M denotes the type of construction of this machine and 10" denotes the diameter of the turbine.

Turbodrilling Method. In Russia there are different types of turbines in use which differ mainly in their number of stages and their diameter. Their over-all length is about 26 feet. The technical data of the types of turbines mostly used at present are shown in Table 2.

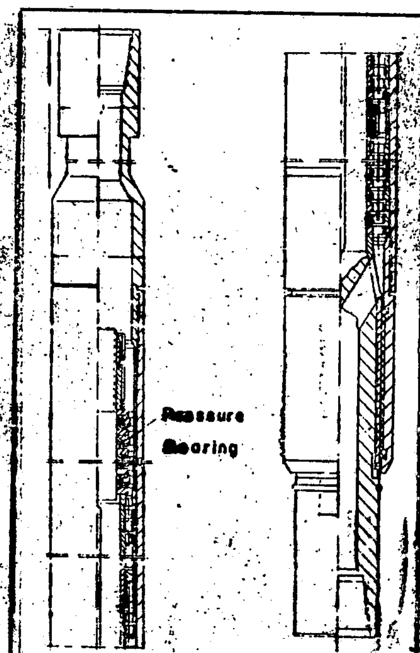

FIGURE 1—A profile of the T-12 M 10-inch turbine.

The pump capacity ranges between 635 and 930 gallons per minute. For example, the 100-stage turbine of type T 12 M 2-10" a turbine of latest design, transmits a torque of 2170 feet per pound to the bit with a pump capacity of 875 gpm. The pump pressure in this case was between 1175 and 1470 pounds per square inch, at a depth of 6560 feet. The pressure in the turbine is proportional to the torque. In this case it was 800 psi.

The number of revolutions of the bit while drilling is about half of the revolutions while idling. The drilling is controlled by a drillometer, a pump manometer and a pump flow meter. The use of a bit revolution counter is also planned. The efficiency of the turbine drill is about 60 percent.

The increase of the pump capacity results in higher revolutions, higher torque, and normally a higher drilling rate. However, there are natural limits to the increase of the pump capacity. Therefore, the diameters of the turbo-channels were enlarged and the pump capacity as well as the torque were increased without creating a higher pressure in the turbine. With these turbines the efficiency was boosted by 15 to 30 percent.

In other experiments the turbine stages were augmented without changing the pump capacity and the pressure inside the turbine. The resulting length made the construction of machines of this kind very difficult from the engineering standpoint. Therefore, initial experiments were made by welding together two turbines of 100 stages each.

In 1953, a prolonged turbodrill,

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T12M2-10" with 150 stages, was buit and tested. About 10 feet were added to the case of the drill. The screw connection was welded together for safety reasons. The over-all length of this new drill was 38 feet. The technical data of the turbodrill T12M2-10" with 100 and with 150 stages are shown in Table 3.

It follows that with a turbine of 150 stages at a pump capacity of 725 gpm a higher bit load is possible than with a turbine of 100 stages at 872 gpm. Comparative values of the capacity of the two turbines are shown in Table 4.

It is interesting to compare a rotary drilling method and a turbodrilling method (150 stages) at about equal conditions: (Note Table 4-A).

TABLE 4-A

	Rotary	Turbo
Drilling Interval	5900-6560	5900-6560
Rotary Table Rotation, r.p.m.	100	.....
Footage Drilled, Feet	69	95.2
Net Drilling Rate, ft./hr.	6.6	21.6

The results show a threefold increase in drilling rate by the turbodrilling method at about one and a half as much total footage.

At the same time a turbodrill TS 1-8" with 190 stages was developed from the already tested turbodrill T12M1-8". The technical data of this new drill are shown in Table 5.

The type TS1-8" transmits a torque of 1725 feet-pounds at a pump capacity of 540 gpm, while type T12 M1-8" at equal pump capacity transmits a torque of 905 feet-pounds only.

Comparing the data of these two turbodrills at different pump capacities in drilling holes of 8200 feet the results are for type T12M1-8" at a pump capacity of 635 gpm, a torque of 1190 ft-lbs and for the type TS1-8" at a pump capacity of 555 gpm, a torque of 1725 feet-pounds. This means an increase of about 50 percent with the section turbine.

This section turbine is built from the parts of the conventional machine T12M1-8". The upper section has 98 stages with 10 pressure bearings while the lower section has 92 stages with 18 pressure bearings. The mounting is done separately. The shafts are put together by a split sleeve consisting of two half sleeves. Figures 3A and B.

Tests were made at the end of 1953 with the new turbine TS1-8". Drilling was begun at [illegible]60 feet at a pumping rate of 507 to 555 gpm. The pump pressure ranged between 1325 and 1620 psi. The bit load was 30,000 to 40,000 pounds. Approximately 1970 feet were drilled. Thirty-three bits were used at an average rate of 52.5 feet per bit. The results of this section turbine were about 70 to 80 percent higher than those of the conventional turbine T12M1-8".

These results show that the problem of increasing the torque seems to be practically solved by augmenting the number of stages. This is particularly important for deeper holes since

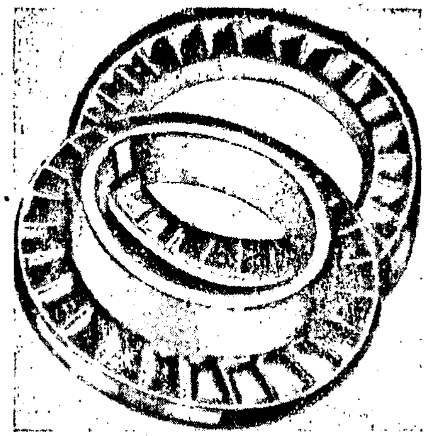

FIGURE 2—A rotor and stator from the T12M 10-inch turbine.

TABLE 2
Technical Data on Turbines Presently in Use in Russia

Type of the Turbine	Circulating Rate in gpm.	Revolutions per Minute	Pressure Inside the Turbine in psi.	Torque in ft/lb.	Diameter in Inches	Length in Feet	Weight in Pounds
T 14 M—9¾	603 634 713	610 640 720	735 808 1014	1150 1272 1627	10.05/9.85	25.5	4340
T 19—10"	603 634 713	520 550 620	735 808 1030	1402 1555 1972	10.5	27.5	4840
T 12 M—8"	555 603 634	600 650 685	603 706 780	882 1040 1150	8.46	27.6	3740
T 12 M 2—10"	713 794 872	550 610 670	603 735 897	1505 1850 2240	10.05/9.85	26.9	5250
T 12 M 1—8"	555 603 634	645 700 735	515 603 662	889 1048 1157	8.35/8.27	28.4	4600
T 12 M 2—8"	555 603 634	590 640 675	515 603 662	851 976 1083	8.19/8.07	27.6	3200

TABLE 3
Operating Characteristics of the T12M2-10" With 100 and With 150 Stages

Number of stages	Pressure Inside the Turbine psi.	Circulation Rate, gpm.	Torque Ft./Lb.	Revolutions per Minute	Efficiency Percent
100	882	872	2170	640	60
150	882	725	2205	520	60

TABLE 4
A One Run Comparison of the T12M2-10" With 100 and With 150 Stages

Type and Size of Turbo-Drill	Type and Size of Bit	Drilling Pressure Psi.	Pump Pressure Psi.	Pump Capacity Gpm.	Average Drilling Rate Ft./Hr.	Total Footage, Feet
T 12 M 2—10"—150	11¾" Three Cutter	147–338	1180–1470	603–665	17.1	78.5
T 12 M 2—10"	11¾" Three Cutter	88–191	1180–1470	714	7.9	46.6

TABLE 5
Operating Data for the TS1-8" With 190 Stages

Pump Capacity* Gpm.	Optimum Revolutions Rpm.	Torque Ft-16	Capacity in Horsepower	Pressure Inside Turbine, Psi.
570	540	1910	191	1045
540	510	1725	162	933
510	480	1490	132	825
480	450	1310	108	726

*Specific gravity of mud 10.0 lb./gal.

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hydraulic losses occur with increasing depth.

The Rigs. The capacity of turbodrilling depends primarily upon the pumps which drive the turbines by the flow of the drilling fluid and keep the hole clean. Until 1950 turbodrilling was impaired by lack of adequate and efficient pumps.

Heavy rigs for rotary and turbodrilling have been developed with which a high drilling capacity can be reached. These rigs are powered by diesel engines and are easily convertible to electric power.

The final developments of modern, heavy, compound, rigs up to 10,000 feet was the type Uralmasch 5D with diesel engines and a total capacity of 1500 horsepower. In addition a new 16,500 foot rig was put to work in 1953 which has a drive of 2000 hp and was equally well suited to either the turbo or rotary drilling methods. The technical data of these rigs are shown in Table 6.

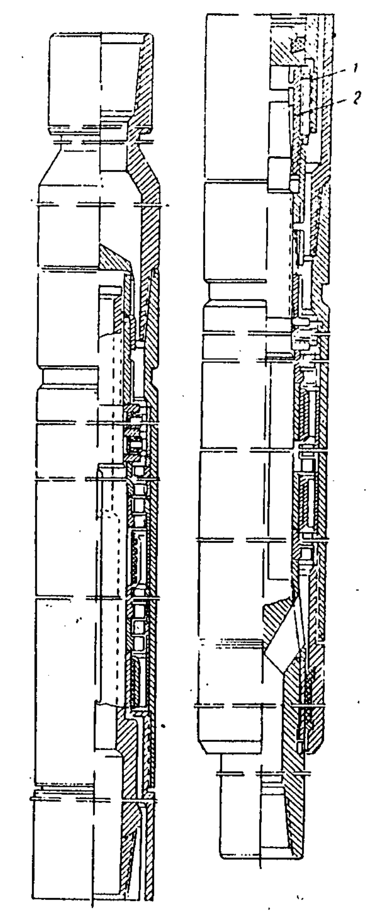
Both drilling rigs are equipped with modern devices for ease of operation and efficiency, including:

- Newly developed rail-pneumatic friction clutches in place of claw and disk clutches.
- Pneumatic operation of the rig.
- The compounding of the engines.
- Hydraulic brakes and pneumatic operation the band brakes.
- The application of duplex-chains upon milled and thermo-treated chain wheels.
- An extra gear for hoisting of the

TABLE 6

A comparison of the capacities of a 10,000 foot (Uralmasch 50) and a 16,500 foot rig (Uralmasch 35).

	Units	Uralmasch 5D	Uralmasch 3D
Carrying Capacity....	tons	130	200
Maximum Depth.....	ft.	10,000	16,500
Capacity, Installed....	hp.	1,500	2,000
For Hoisting.......	hp.	750	1,200
For Mud Pumps....	hp.	1,000	1,000
Maximum Line Pull:			
At the Drum.......	tons	14.5	22.0
Number of Gears.....	..	4	5
Power I. Gear....	tons	100	136
II. Gear....	tons	75	113
III. Gear....	tons	40	63
IV. Gear....	tons	12	38
V. Gear....	tons	.....	25
Number of Gears:			
At Rotary Table....	..	3	4
Rotary Table Speed...	rpm.	79,119 206	43,100 170,260



(A) (B)

FIGURE 3—Cross-section of the section turbine, T 12 M ⅛-inch. The shafts are joined by a split sleeve.

unloaded hook which saves unnecessary shifting by the operator.

- Automatic adjustment of compressor pressure and direct connection of the rail-pneumatic clutch with the compressed air.

Both rigs had operated without trouble and were still in good condition after drilling 16,400 to 19,700 feet. The hard wear on the chain of the hoist was very low. Idle hours caused by repairing of the chain dropped from 5 percent to one percent of the working hours. The aforementioned pumps have been working for four years at a capacity of 800 to 1030 gpm at 1620 psi without trouble. In 1952 the diesel engines had been used an average of 2900 hours.

Circulation When Turbodrilling. When turbodrilling the circulation is of particular importance. Its purpose is not only to bring out the drilled particles or hold them in suspension, or cool the bit, but it serves in particular to drive the turbines.

Special emphasis is placed upon a good drilling mud in rotary drilling, while turbo-drilling requires a fluid free of drilling mud in order to spare the turbines. The lifting ability of rotary drilling fluid must be carefully controlled due to the low annular velocities. This lifting ability does not play an important part in turbodrilling because of the high annular velocities. The high revolutions of the turbine grind the drilled particles very fine so that it can be easily flushed out.

For these reasons the change is toward the use of water in drilling. Also clay has a higher hydraulic resistance. With water as a drilling fluid, it is possible to achieve a higher pumping rate without running into too high pump pressures. At a pumping rate of from 700 to 730 gpm a pressure of 1320 to 1470 is obtained with a clay mud, while with water the pressures are in the neighborhood of 880 to 1030 psi. Any extra particles in the drilling fluid cause hard wear of the parts of the pumps and turbines. The use of water over a clay mud is also much cheaper.

In 1952 the first wells using water exclusively as the drilling fluid were brought in. No jamming or sticking of the drilling tools was reported. The drilled particles were easily circulated out with water.

Initially clay mud was used to drill the holes for the 16-inch and 12-inch casing and then the system was changed to water. The 12-inch was set at from 200 to 820 feet. Since 1953, however, the majority of the wells are drilled from the start with water. See Table 7.

It was found that before pulling the turbine from the hole that it was necessary to circulate for a long period of time so as to avoid settling of cuttings around the bit. No case was reported of a stuck turbine due to the interruption of circulation. In one case tools which got stuck during drilling with clay mud were washed free with water.

A disadvantage of the water drilling is the greater danger of corrosion

TABLE 7

A yearly comparison of drilling rates and footages after the introduction of drilling with water

	1949	1950	1951	1952	1953
Percent of Total Wells Drilled with Water......	......	......	......	12.2	76.2
Average Total Capacity (Ft./Rig-Month)......	1314	1400	1730	1925	2420
Average Footage per Bit in Feet..............	52.2	54.2	52.7	55.5	68.3
Average Drilling Rate in Ft./Hr..............	7.0	8.9	11.0	14.9	34.1

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the tool joints. The joints are lubricated with graphite and made up tight.

In some areas the use of drilling mud could not be entirely avoided. There were clay beds in the Devonian between 4900 and 5250 feet having a thickness of 80 to 100 feet. The water caused the clay to swell and prevented further drilling. In a case like this the change to drilling mud should be done gradually without interrupting operations. Formerly the water was displaced by prepared drilling mud, this took 3 or 4 days, and resulted in fluid losses. The gradual change to a clay base mud can be accomplished gradually in a 24-hour period. In order to assist the initial formation of a filter cake 1320 to 1760 pounds of peat, 440 pounds of clay and 88 to 110 pounds of caustic soda were mixed with water in a mixer and added to the water circulation.

In 1953 a well drilled with water had swelling clay between 5250 and 5400 feet. This horizon was drilled through with an eccentric bit mounted on a bent drill stem (5°) thereby enlarging the hole with this reach. The enlarged annular space was then cemented. After the cement had set the well was continued with water to the intended depth of 5600 feet.

Another method of avoiding the clay contamination of drilling water is fast penetration of the clay beds. On the above mentioned well the clay beds were located immediately above the oil zone. Within 36 hours the clay bed and oil zone were drilled and then cased. During this time no swelling occurred.

An ideal solution of turbodrilling would be to separate circulating fluid and driving fluid. That is, to either drive the turbine by electric power or to part the circulating fluid and the driving fluid.

Drilling Capacity. A comparison between rotary and the turbodrilling methods showed an average increase of 1½ to 2 times the capacity with turbodrilling under analogous geological conditions. This high drilling capacity of the turbodrill was reached by a more efficient transmission to the bit. With rotary tools at 10,000 foot depth with 4½-inch drill pipe, 7½-inch bit turning at 125 rpm, the transmission to the bit was 40 horsepower or about 1.1 hp per square inch of hole. With turbine drilling using 6⅝-inch drill pipe, a 12½-inch bit and a pump capacity of 800 gpm the highest possible transmission to the bit was 200 hp or about 1.7 hp per square inch of hole bottom.

Table 8 shows a comparison of data of several wells brought in with turbines during 1953.

It is interesting in this table to notice how little time was needed for fishing and the good time made for net drilling of wells 321 and 381.

Finally, reference may be made to a record well brought in during the Spring of 1954 in the area of the so-called "Second Baku," located in the Eastern part of European Russia. The following data were reported on that well:

Total Depth, feet...	5580
Total footage in ft./rig/month.......	8580
Total drilling time.	19.5 days (469 hrs.)
Average drilling rate ft./hr............	64.6 (Min. 26.6)
Total footage per bit	113.8
Number of bits used	49
Avg. time on bottom per bit, hrs......	......
Productive working time, percent....	94.7%
Net drilling time, hrs..............	86.
Time for trips, hrs..	153.3
Casing, hrs.........	80.1
Miscellaneous, hrs..	84.4
Unproductive time, hrs..............	24.

This capacity was reached with a rig having three pumps of a total capacity of 1100 to 1200 gpm. The bit load was between 60,000 and 70,000 pounds. Water was used from the surface casing to total depth. On the basis of this experience there are possibilities being studied in Russia at the present time to reach a capacity up to 10,000 feet per rig per month with this drilling method.

Advantages and Disadvantages

• **Faster drilling progress.** The availability of higher working capacity at the bottom of the hole means faster drilling. This advantage remains even when bigger bits than those customarily used with rotary drilling are used.

• **Straighter drilling.** The bit speed in turbodrilling is higher, the bit weight is lower and the neutral point of the drill stem is higher up the collars than when greater weight is used.

• **Full gage drilling.** Since the drill stem does not joggle and the drilling is straight, a hole is made with little bit walking. This is an advantage when running and cementing casing.

• **Low wear on the drill pipe.** The hard wear on the outside of the pipe and the tool joints is greatly reduced because the string rotates in some cases with 10-15 rpm only or in many formations need not be rotated at all.

• **Fewer fishing operations.** Most of the causes for parted pipe are eliminated by turbodrilling. The pipe is not exposed to sudden dangerous momenta like special loads or bending pressure which may occur at any time while rotary drilling. The pipe does not drag on the wall of the hole except at very low speeds. Twisting off does not occur.

• **Fishing of bit cones and other**

TABLE 8

A Comparison of the Drilling Time Break-down for Several Wells Drilled by the Turbine Method During 1953

	DESIGNATION OF PRODUCTION WELLS				DESIGNATION OF WILDCAT WELLS	
	295	316	321	381	528	410
Total Depth of Well, Feet.........	5960	5580	5850	5660	5840	6260
Starting and Completion Dates.....	12/26 2/19	3/18 4/20	5/10 6/ 4	6/19 7/18	8/9 9/22	10/15 12/14
Total Footage Per Rig-Month......	3220	5070	7430	5710	4230	3018
Average Drilling Rate, Ft./Hr......	23.2	24.2	41.5	41.8	28.1	28.7
Number of Bits..................	95	69	62	66	69	67
Footage Per Bit..................	63.9	80.4	94.5	86.6	84.6	93.5
Type of Power..................	Diesel	Electric	Diesel	Diesel	Diesel	Electric
STATEMENT OF WORKING HOURS						
Total Working Time, Hrs..........	1307	800	571	688	997	1404
Productive Time, Hrs.............	1130	758	515	627	898	1145
As Follows:						
Net Drilling Time, Hrs...........	256	230	126	137	208	207
Rig-Up and Tear-Down, Hrs......	388	225	205	230	257	327
Transportation, Hrs.............	50	22	16	21	33	41
Changing, Bits, Hrs.............	47	40	38	57	51	35
Running Pipe, Hrs...............	165	80	68	87	79	168
Miscellaneous, Hrs..............	324	161	62	113	270	367
UNPRODUCTIVE HOURS, Total.	177	42	56	61	99	259
As Follows:						
Fishing and Down Time, Hrs.....	14	....	....	....	....	3.9
Maintenance....................	91	24	30	23	32	77
Waiting on Cement, Etc., Hrs....	72	18	26	38	67	143

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parts of bit does not happen so often.

- **The danger of twisting off** is always present while rotary drilling because of its high speeds. Furthermore, the formation of keyseats is another frequent cause of fishing operations. While turbodrilling this happens less frequently because the hole is straighter and the stems turn slowly or not at all.
- **For turbodrilling** the most frequent cause of fishing operations is falling, swelling, or flowing rock formations. However, a straight hole, tension loaded drill stem, and very low rotative speeds of the stem reduce this danger very much. Turbodrilling does not create any new drilling difficulties and eliminates most of the existing difficulties of rotary drilling or reduces them to a great extent.
- **Less strain on the rig.** The strain on the swivel and the rotary table is considerably reduced. The mast base vibrates only slightly. This results in a reduced strain on the rig in general.
- **A clean hole.** The lifting capacity of the drilling mud is improved by the higher annular velocity. The drilled particles are of finer grain because of the higher speed of the bit, and can be brought out better.
- **Interchangeability.** The turbodrilling is interchangeable with the rotary-drilling method.

Disadvantages of turbodrilling. If difficult drilling conditions prevail requiring a heavy and viscous mud the turbodrill cannot be applied as long as these special conditions exist.

For turbodrilling the speed of the bit varies between 200 and 600 rpm. Therefore it is possible that certain beds may not be drilled as well as with rotary methods at a bit speed of 50 to 70 rpm. The final answer, however, could only be given after extensive drilling experience.

Strain to the mud pumps. The strain to the mud pumps will be higher because the pumps have to perform more for turbodrilling. For this reason it is necessary to keep the sand content of the fluid as low as possible. For practical purposes a sand content of less than 3 percent by volume is considered good.

Either as general successor of, or as supplement to, the rotary-method the turbodrilling method promises to contribute an important share towards increasing the capacity and rentability of deep drilling. —The End

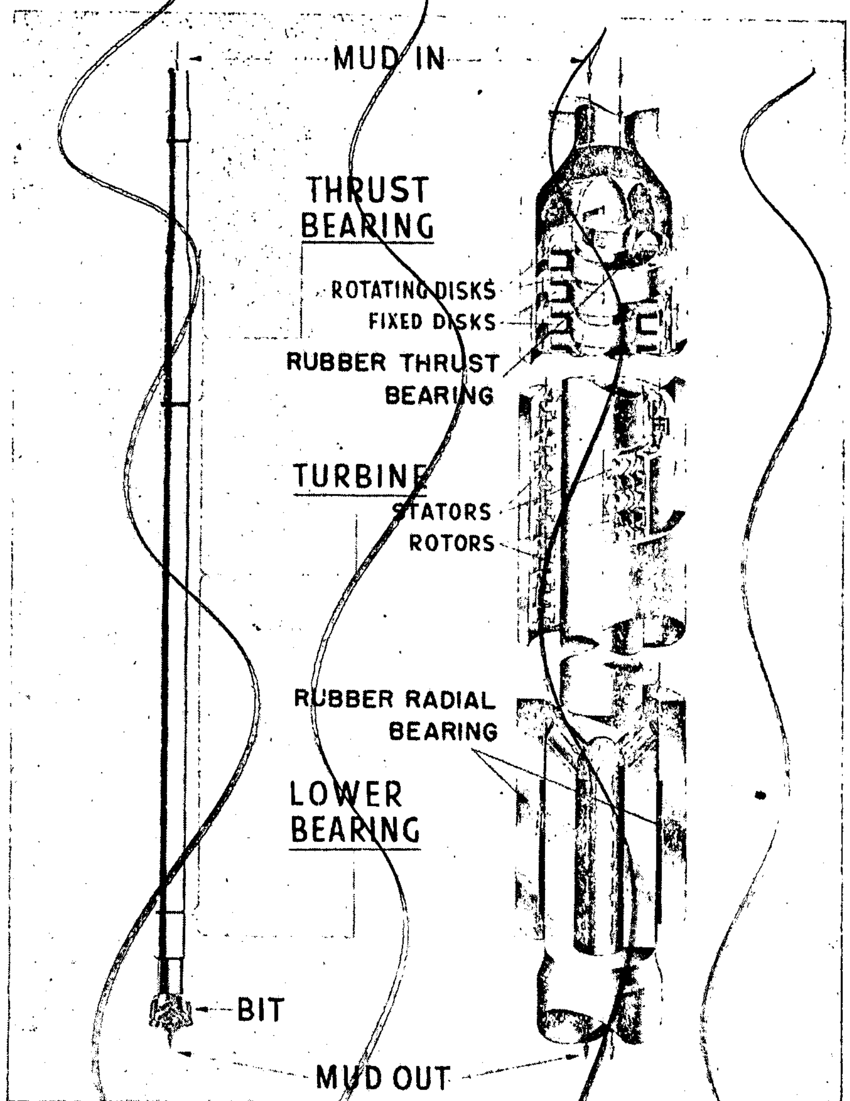

FIGURE 1—Cutaway drawing of turbodrill showing the important components and operational features.

Russian Turbodrills . . . How Good are They?

How do Russian technological advances compare with those of the U. S.? Russian turbodrills now in Dallas will soon be tested against American rotary equipment.

In recent months the drilling industry has become increasingly aware of the possibilities inherent in having a down the hole source of power for driving the drill bit. Scattered and unsuccessful tests have been carried on in the U. S. since 1873, but only recently with reported success of Russian turbodrilling has there been much widespread interest in this method.

Now, tool manufacturers and drilling personnel alike are anxiously awaiting the results of tests presently

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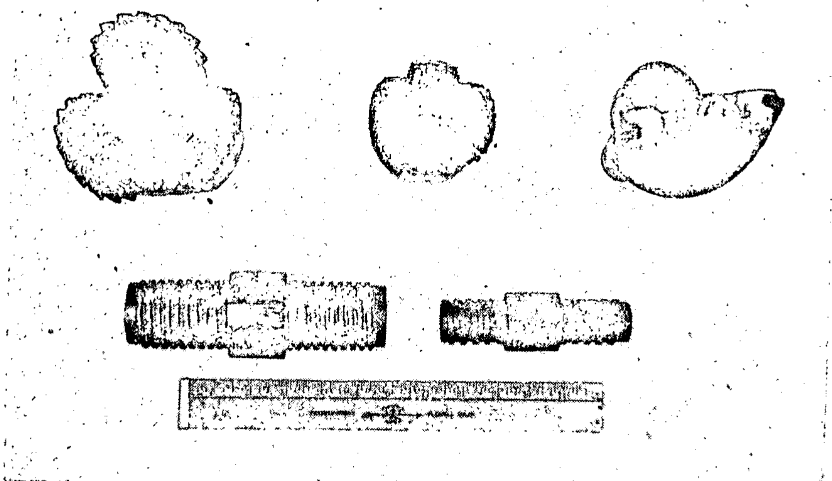
New California Approach In Landslide Control



● Figure 1 — Upper 4-1/2-in. rock bit, 3-1/8-in. rock bit, and 4-in. fish-tail bit with tungsten carbide inserts. Lower N-rod coupling and A-rod coupling.

Low cost is a feature of the methods here described, which are applicable in formations permitting use of standard drilling equipment.

By A. W. ROOT

Supervising Materials and Research Engineer,
California Division of Highways, Sacramento

THE avoidance, prevention and control of landslides constitute an important phase of highway design, construction and maintenance in California. There are numerous types of landslide, which have been variously classified according to kind of material, type of movement, causes and a great many other factors.

Probably the most prevalent type of landslide, and the one which is most troublesome to highway engineers in California, is the "slump" type. In this type of landslide the movement occurs along internal slip surfaces, and characteristically the surface cracks are concentric, and concave toward the direction of movement; the top surfaces of the moving blocks or units are often tilted backward toward the slope; the surface of rupture may approach an arc of a circular curve, concave upward, but the shape of the curve is greatly affected by any discontinuities in the material. Most roadway slipouts are slump-type landslides.

The factors or conditions conducive to land movement are numerous, and it is seldom that one "cause" can be assigned to a landslide. Nevertheless, it is generally agreed that ground water is a major contributing factor in the vast majority of slump-type landslides in California. Ground water may act in several ways to induce land movement: the activating forces are increased by hydrostatic pressure or by seepage forces; in the presence of ground water, resisting forces are reduced by pore pressure or by lower shear strengths of the soil.

Interception and removal of subsurface water is often an effective method of preventing or controlling landslides, especially the "slump" type. One method of subdrainage used extensively in California consists of installation of horizontal drains, which are 2-inch perforated pipes placed in drill holes bored into a slope. The drains are usually 100 feet to 300 feet in length, and on gradients varying from 1 percent to 20 percent. Horizontal drains are frequently, but erroneously, described as "Hydrauger" drains. "Hydrauger" is the proprietary name of one type of drill used for installing horizontal drains.

One of the principal advantages of the horizontal drain method of controlling landslides is the relatively low cost compared to other methods of stabilization. The use of horizontal drains is restricted to soil formations which can be drilled economically with available drilling equipment. Constant efforts to improve methods and drilling equipment have made possible the economical installation of horizontal drains in all but the most difficult formations.

For several years all of our drilling was done with "Hydrauger" equipment and some of these units are still in use. Diamond* drill A-rods are used with these drills; all of our earlier drilling was done with fishtail or auger-type bits having tungsten

This article appeared in California Highways and Public Works, March-April, 1955.

*This is a name designating standard core drill fittings, which may be used with any type of drill bit. Diamond-set bits, although used for coring solid rock or concrete, are not normally used for drilling horizontal drains.

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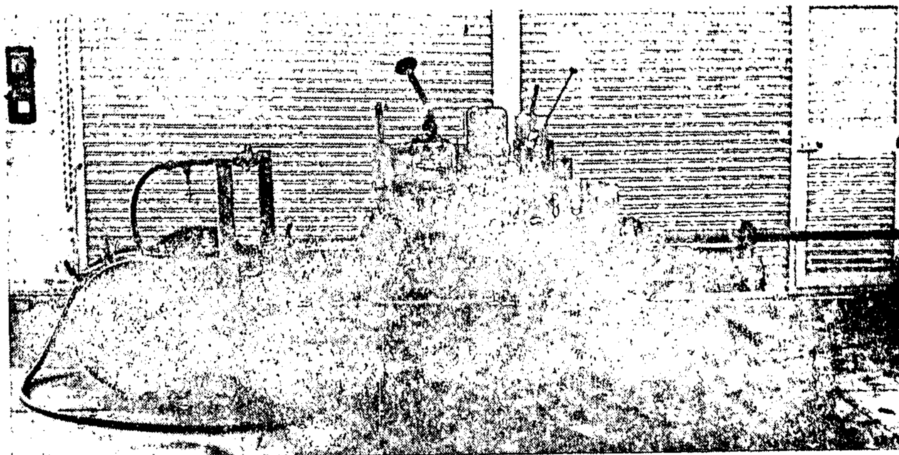
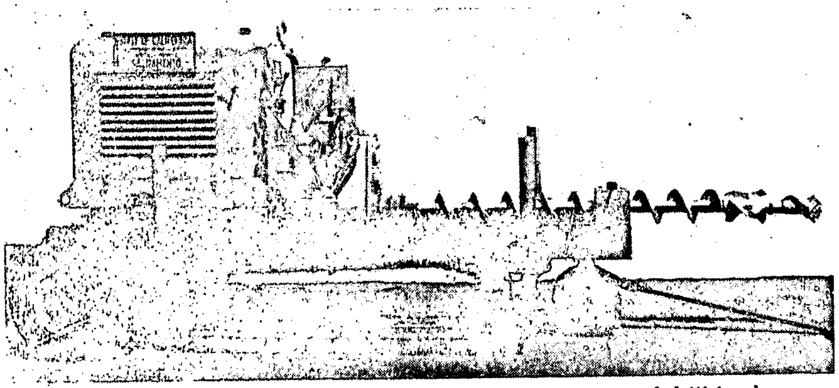
carbide inserts. These bits were made up in our own shops. When small size oil-field type roller bits became available we experimented with them and found them greatly superior to the fish-tail and auger bits for drilling rocky formations. Accordingly, we adopted the roller-type bit for all drilling except in rock free earth. Figure 1 shows the rock bits and fish-tail type bit.

Adoption of the roller type bit enabled us to drill to greater depths and through more difficult rock formations which could not be penetrated with the fish-tail and auger bits previously used. But at the same time the more difficult drilling increased power requirements and caused greater stresses



● **Figure 3 — California horizontal drill with drill rod and bit in drilling position.**



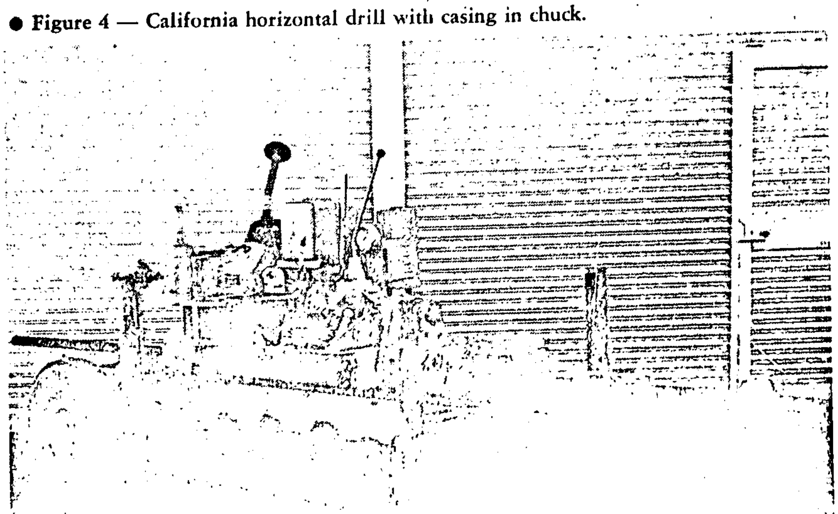
● **Figure 2 — McCarthy rock-boring machine with helical auger and drill head.**

on both the drill rods and the drill unit. As a result, breakage of the A-rods became excessive, and it was found that the Hydrauger air motors did not supply sufficient power. The type of drilling which we can do with the rock bits appeared to require a more rugged and more powerful drill unit than the Hydrauger which had been used exclusively in the past.

Our first attempt to use heavier drilling equipment was with the McCarthy Rock Boring Machine shown in Figure 2. This drill, which was designed for use with continuous helical augers, drills rapidly in earthy formations, but cannot drill to depths greater than about 150 feet, nor will it penetrate broken rock formations. By means of a water swivel fabricated in Headquarters Shop of the Equipment Department the McCarthy machine was converted to a rotary type drill, using diamond N-rods and a 4½-inch roller type rock bit. Figure 1 shows the relative sizes of the A-rod and N-rod. The converted machine operated very satisfactorily, and we found that the use of heavier drill rod, the hydraulic feed and superior power all were advantageous. This machine, however, had one serious drawback: when using the machine for forcing the casing into the drilled hole, the casing must be in front of the drill carriage, as the design of the machine prevents working through a chuck; this necessitates using lengths of casing which can be inserted between the carriage and outlet end of the drain at the ground surface. In restricted working areas it is necessary to use five-foot lengths of casing, with a correspondingly large number of field welds. Also the McCarthy machine is somewhat larger and more powerful than necessary for the rotary drilling work on our drain installations, which results in some sacrifice in mobility.

We could find no drill rig on the market designed specifically for drilling holes for horizontal drains, and none which satisfied our requirements. We desired a drill rig incorporating the following features: the drill unit should be complete with a gasoline engine of adequate power; a suitable transmission to permit control of speed of rotation over a wide range; a hydraulic feed with a minimum stroke of six feet, capable of exerting a 4,000-pound thrust; provision for slowly rotating the casing concurrently with the jacking operation when necessary; a chuck readily interchangeable for A-rod, N-rod or casing and so designed that long lengths of rod or casing can be operated through

● **Figure 4 — California horizontal drill with casing in chuck.**



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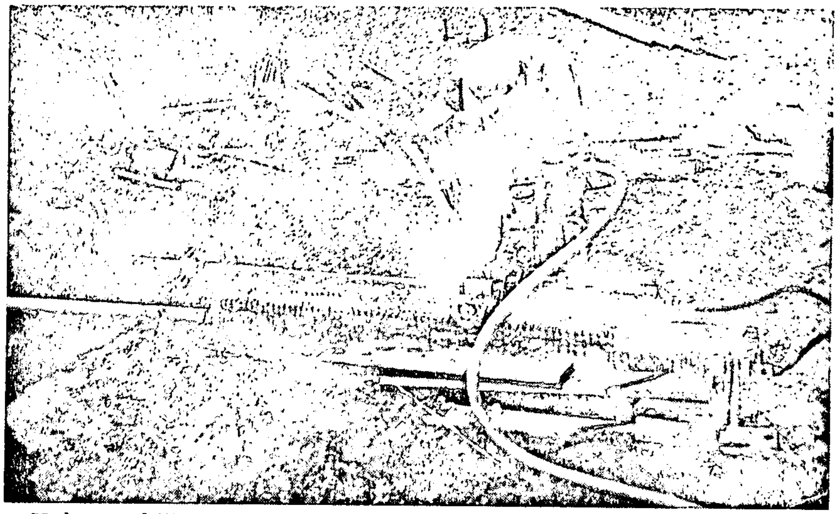
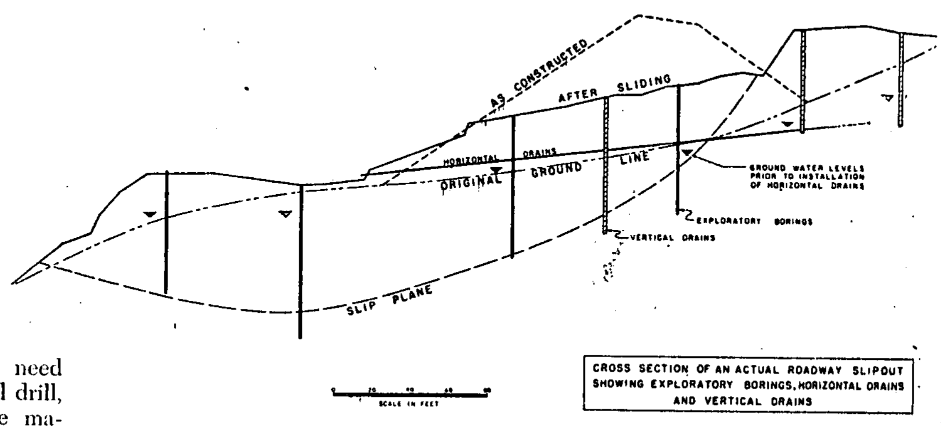


● **Hydrauger drill in operation.**



CROSS SECTION OF AN ACTUAL ROADWAY SLIPOUT SHOWING EXPLORATORY BORINGS, HORIZONTAL DRAINS AND VERTICAL DRAINS

the chuck; rugged but easily operated spuds for maintaining alignment and grade of the drill; rubber-tired wheels and three-point suspension to permit sharp turns; and, finally the over-all length not to exceed 12 feet and the weight of the complete drill to be not more than 3,000 pounds.

The Materials and Research Department had for several years realized the need for such an improved horizontal drill, and as no completely suitable machine could be purchased, it was decided to design and build a drill unit specifically for horizontal drilling. Accordingly, the Equipment Department was requested to design and build a machine meeting the specifications outlined above. As a result of this request Mr. Jim Keleher, equipment design engineer, was assigned by Equipment Engineer Earl E. Sorenson to do the job. Mr. Keleher, with the cooperation of the author and other personnel of both the Equipment and Materials and Research Departments, began designing the rig in January, 1954. By March, 1954, the final drawings had been completed for a machine having the desired features and meeting our specifications; on June 30th the shop had completed its construction.

The new drill rig, for the most part, is comprised of standard or proven parts or subassemblies similar to those used in manufactured drills. The machine is unique because it incorporates the desirable features of various machines into a light-weight, compact drill rig especially suitable for the type of drilling required for installation of horizontal drains. The power unit is a 20-h.p. Wisconsin four-cylinder, air-cooled engine, connected through a fluid drive to a four-speed Ford transmission. Rotation of the chuck is accomplished by a gear train from the transmission enclosed in an oil-tight housing. The entire drive assembly is mounted on a hydraulically operated carriage with a travel of six-feet. A Vickers 10-gallon-per-minute oil pump, driven by the Wisconsin engine, supplies oil to two hydraulic cylinders, by means of which the thrust can be controlled at any desired feed pressure up to 4,000 pounds.

A specially designed chuck assembly was required to permit the use of long lengths of drill rod or casing, and to provide for interchanging chucks for different size rods. Standard A-rod and N-rod chuck heads are used, with a shop-designed chuck holder which permits quick change of chuck heads. A special chuck for gripping the two-inch casing is used in the same chuck holder. The completed drill rig is shown in Figure 3 and Figure 4.

During the design of the machine many difficulties were encountered. Because these problems were solved on the drafting board rather than by cut and try methods, very few modifications were required after the machine was fabricated. The cost of constructing the drill did not exceed the preliminary estimate.

On completion of the drill rig it was taken to American Canyon on U. S. 40 in Solano County for its first operational test. During this test it performed satisfactorily, and has since been used on two other horizontal drain jobs. One of these installations was in District V on San Marcos Pass where the new California horizontal drill rig was used exclusively. Eighteen drains were installed at this location, five of which were 300 feet or more in depth and 7 others at least 250 feet deep. This drilling was done at a very reasonable unit price, comparatively speaking, and the drains were very successful in intercepting the subsurface water. The ease with which this work was accomplished by the new drill rig was a new experience and a great satisfaction to every one associated with it.

As was expected, operation of the new drill revealed some "bugs"; however, only a few minor changes were found necessary and these are currently being made. The satisfactory performance of this first drill unit and its freedom from defects attest to the soundness of design and the high quality of workmanship. All personnel who participated in the conception, design and construction of this new horizontal drill are to be commended for their ability and efforts.

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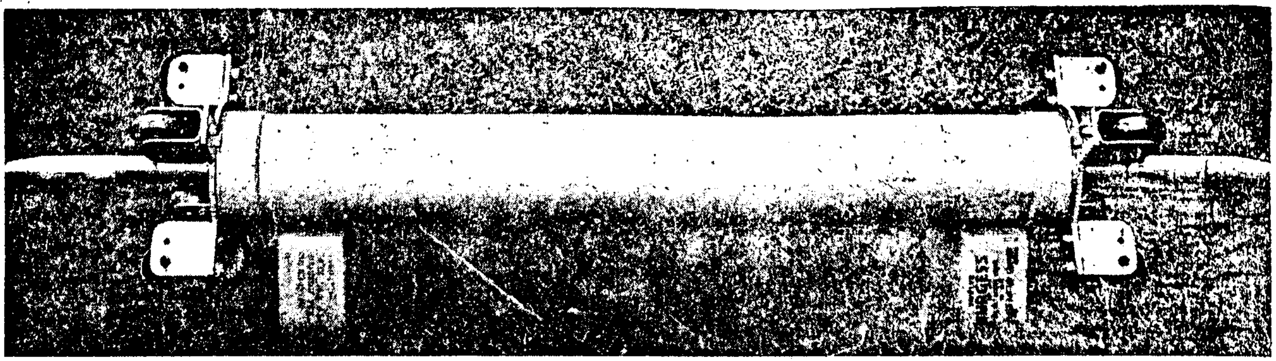
14

THE MOLE . . .



The Mole ready for action. It is pulled through the underwater crossing 40 ft at a time. At each station it takes "shots" of the pipe line slope and direction.

. . . what it is

. . . how it works

W. F. Krueger
Sperry-Sun Well Surveying Co.
Houston, Texas

Basically, the instrument performs much the same tasks as a surveyor's level, transit and chain — *inside the pipe* on underwater river crossings.

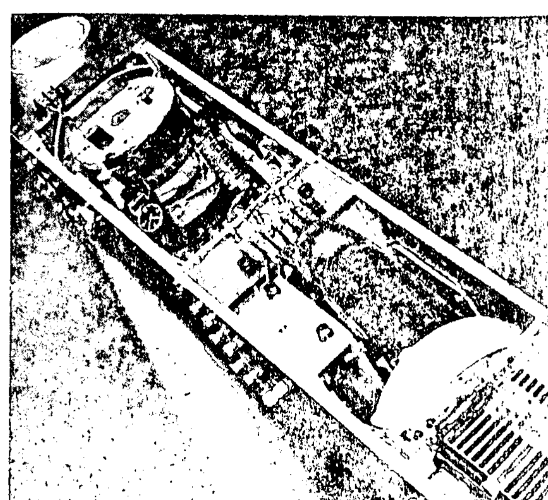
"WONDER what's happening to our Mississippi (or any other large river) crossing?" This is a question that pops up frequently in the minds of pipe line engineers. For underwater river crossings have been known to wander.

From the time a crossing is first laid in its underwater ditch several forces act to displace it. While it is being backfilled the buoyancy of the heavy clay or silt slurry tends to float it upward, and sometimes the banks of the ditch and even the back fill material tend to slip or cave. Even after the line is successfully backfilled, the river can scour beneath it, displace it and again backfill it.

For example, not long ago a certain company had to make repairs on its Red River crossing. At the point where a new tie-in was to be made, the line had virtually disappeared. After a special pipe locator was devised, the line was found more than 100 ft from its original location. The river had scoured beneath the pipe, moved it to a new location and deposited a new sand bar over it.

To solve this problem Sperry-Sun working closely with several pipe line engineers developed the "Mole". This new instrument is simply a modified version of an existing oilwell surveying instrument. For some years the oil industry has been drilling directional holes with uncanny accuracy, and the backbone of this technique has been the directional surveying instrument. It is this selfsame instrument that is the heart of the Mole.

The primary problem of develop-



Inner workings of the Mole. Batteries in the right foreground and electrically timed camera just ahead focused on inclinometer and gyro verniers and clock. Inclinometer reads angles correct to 3 min; gyro correct to min.

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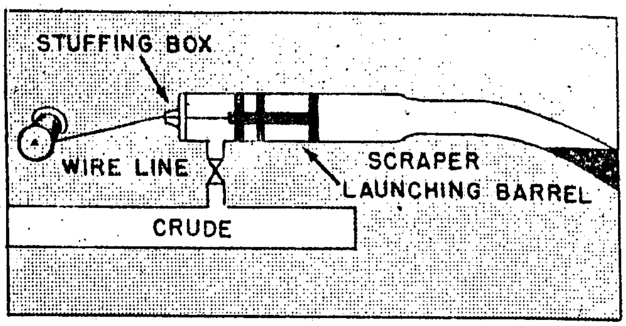
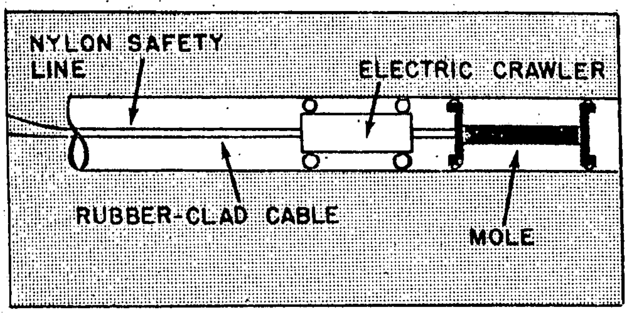
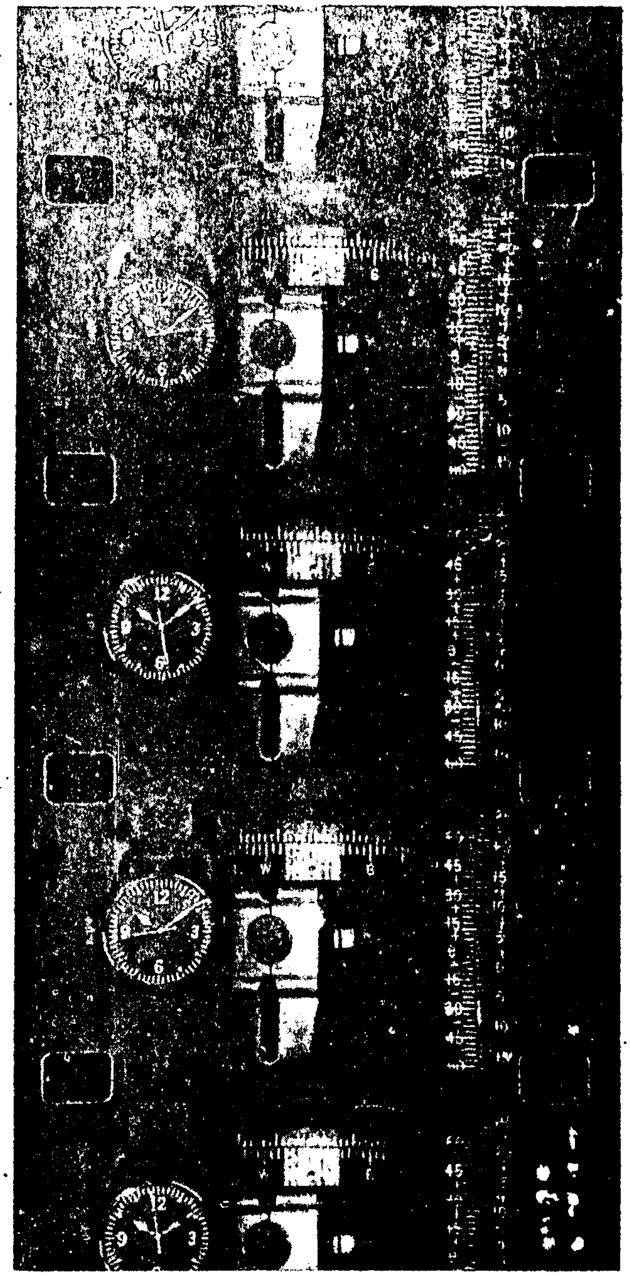




Two ways of propelling the Mole through the line. Top shows a pig pulling a wire line through the crossing, which will later be used to pull the Mole through. Bottom shows electric crawler pushing the Mole through the crossing. In this instance, the rubber-clad cable is used for measurement.



Film record of the crossing shows instrument readings, which are taken every 40 ft or so. From these readings, IBM digital computers calculate Mole's path. Elevation closure to known end elevation averages about 1.2 ft per 100 ft difference.

ment of the Mole was to modify the instrumentation and field techniques of the oilwell surveying instrument (known as a "Surwel") to survey horizontally rather than vertically.

Basically, the instrument performs much the same tasks as a surveyor's level, transit and chain — **inside the pipe!** The level is replaced by an inclinometer, the transit by a gyroscope, the chain by wire lines, wire line meters and synchronized watches, and the surveyor himself is replaced by a movie type camera. The latter photographically records the three elements needed to obtain a pipe line survey. The direction element is the gyro and its scale and vernier provide bearings to 10 min of a degree of an angle. The vertical angle element is the inclinometer and its scale and vernier provide slope to 3 min of angle. The time of the record obtained by photographing the watch indicates the location of the Mole in the pipe line.

These instruments, parts, and other accessories all are mounted in a framework called the cradle. The cradle is supported inside a vapor-tight protective casing so that it acts as a plumb bob. Although the casing might rotate as it travels through the pipe, the cradle remains pendulous to permit proper functioning of the instrument parts. Also inside the case are dry cell batteries that supply the electricity needed for illumination of the instrument scales and for a timing device that single frames the camera every 15 sec. Once the operator starts the Mole it is self-contained and self-operated.

The instrument is designed primarily for use with two wire lines runing through the crossing. One line pulls the unit while the other serves as a back-up. Other forms of motive power are available, however, and eventually all of them will be used. An electrically driven pipe line crawler propelled the Mole through two 30-in. crossings of the Atchafalaya River. Also fluid drive in a crude or products line could provide the required motive power.

How the Survey Is Made

The first step in making a survey is to pull a wire line through the pipe line

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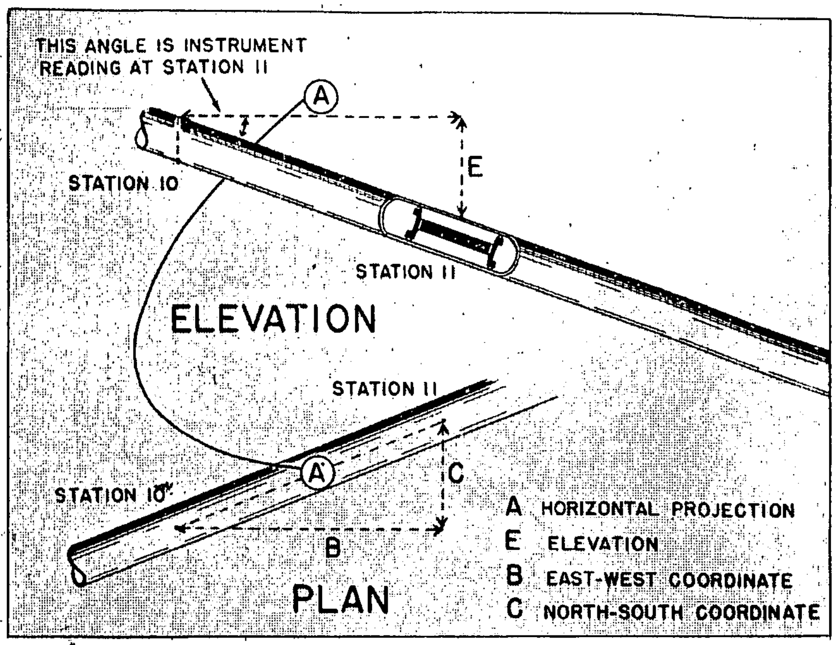


Mole performs tasks of surveyor with level, transit, and chain. Distance from station 10 to station 11 is usually 40 ft measured along the line. From inclinometer reading (correct to 3 min of degree) the elevation difference "E" and the horizontal projection "A" are calculated. Horizontal projection "A" is transferred to plan of line and from the gyro readings (correct to 10 min of degree) the East-West (across river) coordinate "B" and North-South (up or down stream) coordinate "C" is calculated. Later, after return run of Mole, the two surveys are closed against known values of coordinates at crossing ends.

with a pig, compressed air, line fluid, or gas. If a crawler is available there is no need to place the wire line through the pipe.

The surveying begins after the operator has checked his instruments, started and oriented the gyro on a known direction, loaded and started the camera, and synchronized the instrument with surface watches. The cradle is then placed inside the outer casing and the end plates are bolted to the casing. Wire lines and swivels are attached to the end plates, wire line meters are placed on the lines at either end of the crossing, and the survey is begun.

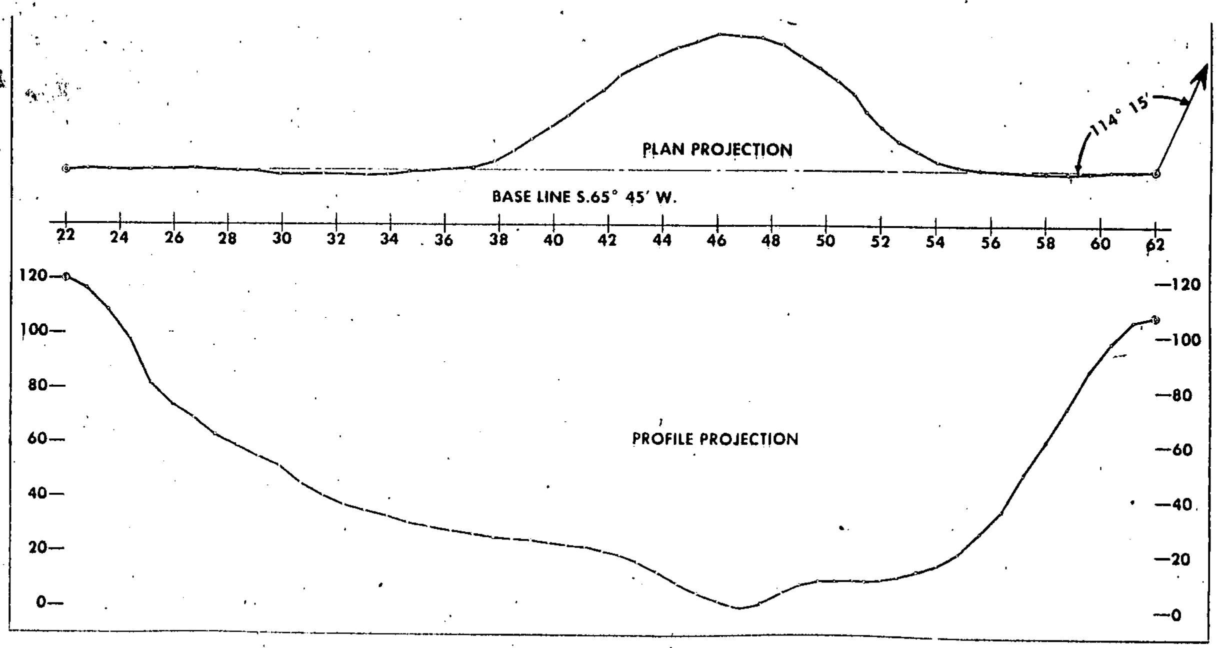
The Mole is pulled 40 ft and stopped for 25 sec to obtain at least one still record of the instrument readings. After the 25-sec pause, the Mole is advanced another 40 ft. This procedure is successively repeated until the entire length of the crossing has been spanned.

After the forward run has been completed, a reverse survey run is made, using the same increments and stopping at the same stations as the forward run.

The survey interval can be longer or shorter than 40 ft depending upon the pipe condition, but it has been found that this interval produces a reliable survey. Where there are short radius side, sag, and overbends the interval is usually decreased to 10 ft in order to detail more accurately these sections.

The survey film is developed as soon as possible after the field work has been completed. Records are read at each survey station to obtain pipe slope and direction. This information is tabulated for both the forward and

Typical plan and elevation of crossing calculated from Mole runs. Horizontal scale 1 in. = 200 ft. Vertical scale 1 in. = 20 ft.



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A	B	C	D	E	F	G	H	K
016	02 00 —	S 70 40 W	.349 —	9.724W	2.305 S	52.676 —	355.078W	87.756 S
017	02 15 —	S 77°30 W	1.570 —	39.022W	8.651 S	54.246 —	394.100W	96.407 S
018	01 12 —	S 76 30 W	.838 —	38.886W	9.336 S	55.084 —	432.986W	105.743 S
019	00 09	S 75 40 W	.105	38.755W	9.902 S	54.979 —	471.741W	115.645 S

Example of IBM run sheet showing station number, A; slope or vertical angle, B; pipe direction, C; elevation increment, D; east-west increment, E; north-south increment, F; cumulative unadjusted elevation, G; cumulative unadjusted east-west coordinate, H; and cumulative unadjusted north-south coordinate, K.

reverse runs and then the two runs are compared to verify instrument performance.

Three dimensional coordinates of each end of the crossing are needed before the survey calculations can be made. Then computations are made for each station of the survey in a manner similar to a land surveyor's calculations. Pipe slope and measured length are used to find the elevation change, and horizontal distance of each survey leg. Horizontal distance and pipe direction are then used to find the horizontal coordinates of each station.

The forward and reverse runs are computed independently to determine the unadjusted coordinates of the survey end point. The difference between computed coordinates and known values is expressed as closure, and each survey is closed on the known end point by applying a straight line adjustment for the three closure corrections. The forward and reverse surveys are averaged to obtain a composite survey, and this survey is plotted in both plan and profile projections.

How Accurate Is the Mole?

These closure values are an indication of survey accuracy. The accompanying table shows the three closure values for the last 10 survey runs (5 pipe lines) of the Mole. These values are expressed in feet and also in percentage of measured pipe length.

		CLOSURE VALUES					
		Elevation		East—West		North—South	
Survey number	Crossing length measured distance	Feet	% measured distance	Feet	% measured distance	Feet	% measured distance
6 In-run......	1541	2.43	0.16	13.80	0.90	8.50	0.56
6 Out-run.....	1541	2.12	0.14	13.94	0.90	8.39	0.54
7 In-run......	1510	3.34	0.22	3.68	0.24	1.27	0.08
7 Out-run....	1510	4.55	0.30	3.69	0.24	2.12	0.14
8 In-run......	3484	0.40	0.01	7.46	0.21	8.25	0.24
8 Out-run....	3484	2.66	0.08	9.44	0.27	2.27	0.07
9 In-run......	3493	2.56	0.07	25.78	0.74	7.24	0.21
9 Out-run....	3493	3.53	0.10	27.80	0.80	16.25	0.47
10 In-run......	8900	8.08	0.09	19.71	0.22	11.10	0.12
10 Out-run....	8900	3.71	0.04	25.15	0.28	10.11	0.21
Average.....			0.12		0.48		0.26

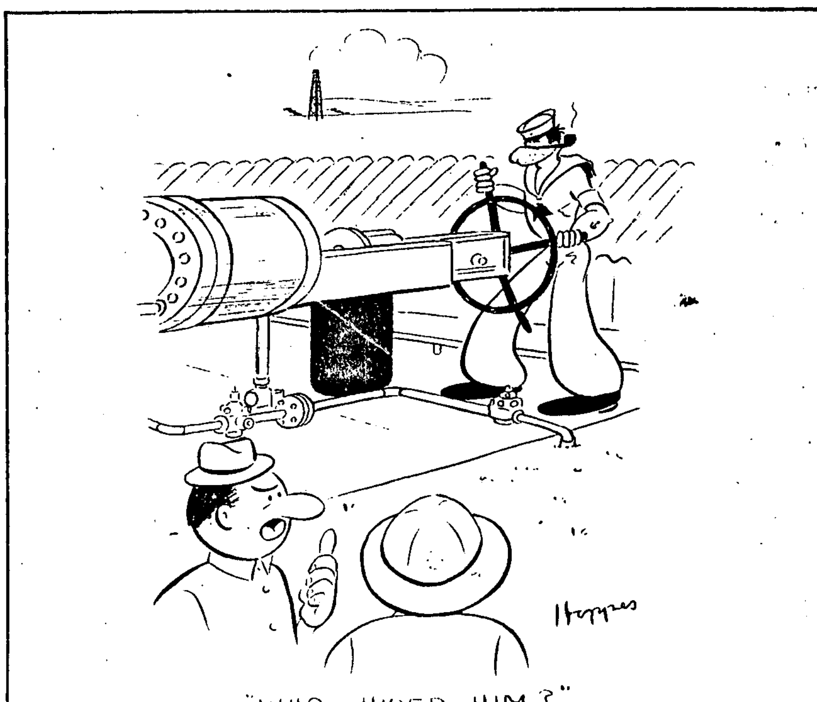
In actual practice, these computations are made on IBM digital computers. This speeds the final survey projections and eliminates computational errors.

To date, the Mole has been used to survey 10 river crossings. All were performed during the instrument's first year of operation. Three of these pipe line surveys were on Atchafalaya River crossings and the other seven were on Mississippi River crossings. Three of the crossings were old lines and seven were new. The size of the lines ranged from 16 to 30 in. and the length varied from 1200 to 9000 ft. The lines were filled with air-natural gas or crude oil.

Six of the new lines had been spot checked at favorable positions for elevation by lead lines, fathometer, and even divers. A comparison of the elevations so obtained with those of the Mole on its run tied in so closely that the small differences could not be directly attributed to either method of measurement. ★ ★ ★

The Author

W. F. Krueger is a native of New York City. He moved to Oklahoma in 1931 to enter Oklahoma University where he graduated as a petroleum engineer in 1935. He worked three years for the U. S. Bureau of Mines at the Petroleum Experiment Station in Bartlesville, later joining Sperry-Sun Well Surveying Company in a sales and engineering capacity. In January 1954, he set out to revamp oilwell surveying instruments to make horizontal pipe line surveys for underwater and marine lines. Since then he has run surveys on 10 river crossings.



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panying table (Fig. 335a). Many bank-run sands and concrete sands and gravel aggregates will meet these requirements. Graded crushed stone not of a self-cementing nature may also be used. Material having not more than 10 per cent of its weight in particles larger than ⅜-in. size, but otherwise meeting the No. 1 gradation, will make a satisfactory filter. It is important that the fine material be in contact with the sides of the trench throughout the water-bearing strata, thereby preventing washing of soil fines from the trench walls and clogging the coarse filter and the pipe.

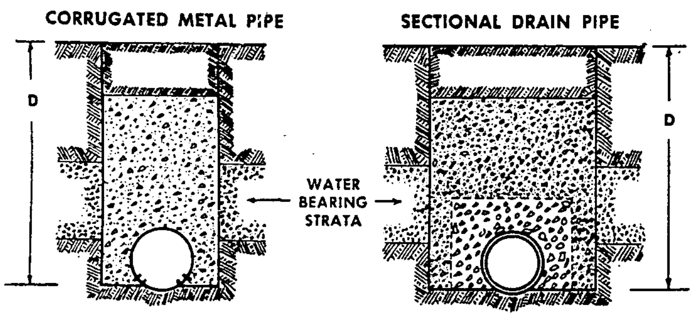
Filter material should be placed in layers and should be tamped. Filter material should be carried to within 6 in. of the ground surface, and the remainder of the trench filled with earth thoroughly compacted. Where surface interception is desired and silting not likely to occur, the filter material can be carried to the surface.

When subdrain pipes with open joints (instead of perforations) are used, it is generally necessary to use two different backfill materials. A coarse filter material (No. 2 on chart) is placed around the pipe to prevent the entrance of fine material into the pipe. Second, the fine filter material described above must be used to prevent washing of soil fines from the trench walls.

Where perforated short-sectional clay or concrete pipe is used, the joints between sections must be filled with cement mortar. Merely laying burlap or roofing paper over the joints will not prevent entrance of the fine graded filter material.

Retaining Walls and Abutments

Perforated corrugated metal pipe installed as drains for retaining walls and for the back of bridge abutments must be installed in a backfill of pervious material as indicated for underdrains or subdrains. While drains may be placed on more than one elevation for high abutments, the bottom drain should be placed at the lowest level that will drain when water in the stream is at normal low water level.



ONLY ONE FILTER GRADATION NEEDED: Gradation No. 1 is used to prevent migration of soil particles from trench wall which would cause silting of underdrain and settlement of surface.

TWO FILTER GRADATIONS REQUIRED Gradation No. 2 is necessary in conjunction with Gradation No. 1 to prevent fine filter material washing into large opening at joints and clogging the pipe.

Depth "D" should be varied to suit installation conditions.

FILTER * GRADATION	PERCENT PASSING STD. A.S.T.M. SIEVE							
	1½	1	⅜	No. 4	No. 8	No. 16	No. 50	No. 100
No. 1	—	—	100	95-100	—	45-80	10-30	0-10
No. 2	100	90-100	25-60	5-40	0-20	—	—	—

*C.A.A. Recommended Filter Gradations.

Fig. 335a. Recommended filters for two types of subdrains—perforated and open joints.

CHAPTER FIFTY-FOUR

Jacking

NEW openings for culverts, sewers, conduits, underpasses, etc. are frequently required under existing railroads, highways, streets, runways, levees and other engineering works. Four methods of placing such openings are: open trenching, jacking, tunneling and boring. These methods are discussed in this and following chapters.

Open trenching is the most commonly used method and is well adapted to new construction and to replacements under shallow fills and areas of light traffic. This method is described in detail in the preceding chapters.

The *jacking* method of installation, in use for the past quarter century, offers important advantages such as protection of the general public and expensive surface installations, and fast, uninterrupted movement of traffic. Fig. 336.

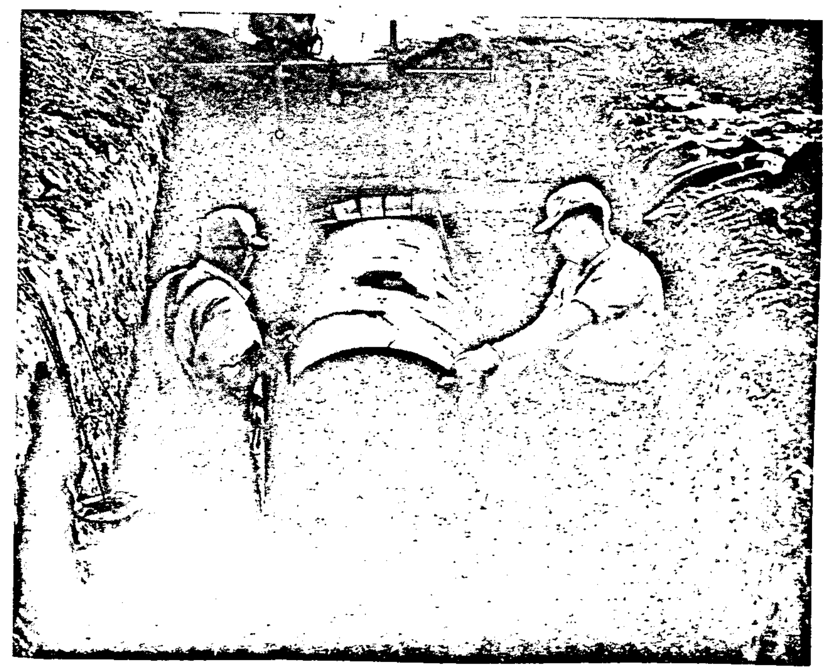


Fig. 336. Jacking provides an efficient means of installing culverts under busy thoroughfares.

No. 17

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Diameters

Diameters of pipes from 28 in. up to 96 in. have been installed by the jacking method with no settlement of surface structures and no interruption of traffic. However, the most common sizes being jacked today range from 30 to 60 in. One essential of this method is that the structure be large enough to allow working space for a man to excavate ahead of the pipe without being too cramped and 36-in. diameter seems to be the minimum for the average size man. The maximum size that can be jacked depends on several factors of which the main ones are: ground conditions, height of cover and safety.

Lengths

The length of pipe that can be jacked is variable and depends on the pipe diameter, ground conditions and the pressures required to push the pipe. Therefore, a thorough investigation should be made of these factors before setting up a job which is to be done entirely by the jacking method. Lengths of over 200 ft have been installed by this method, but ground conditions had to approach the ideal and the pipe had to be kept in motion on a 24-hour basis to keep it from "freezing" tight. Where the pipe does "freeze up" it is possible, under most conditions, to move to the opposite side of the fill and to jack the balance of the pipe to meet the end that is already in place. To do this and make a proper junction of the two pipes, it will be necessary for line and grade to be accurately set and closely watched.

Depth of Cover

The cover over pipe to be jacked on railroads should be at least one diameter. with a minimum of 3 ft to get below the ballast line and into stable material. Under highway slabs that are reinforced, the cover can be a minimum for providing a cushion between bottom of slab and top of pipe. However, under bituminous type pavements the cover should be equal to that used under railroads.

Acceptance

This method of installing new openings has become standard procedure for most railroads and numerous highway departments and has resulted in saving time, money and material, plus a factor of safety which is all-important to present day movement of traffic. Jacking also avoids the cost and nuisance of repeated maintenance of the fill due to settlement which is usually necessary when the open trench method of installation is used. For levee or dike installations jacking avoids sacrificing valuable land and the building of new set-back levees.

Jacking Procedure[1]

Testing of Soil

Jacking should not be attempted in dry sand, in gravelly soil that is known to contain large boulders, through fills where logs or stumps are known to exist or where it is impractical or uneconomical to lower the water table below the excavation.

In all questionable soil conditions, the soil should be tested by boring or sampling before jacking is decided upon. This is neither costly nor time-consuming.

Approach Trench

When pipe is to be jacked through fills higher than the diameter of the pipe, plus the required minimum cover, no working pit is necessary. However, it is desirable

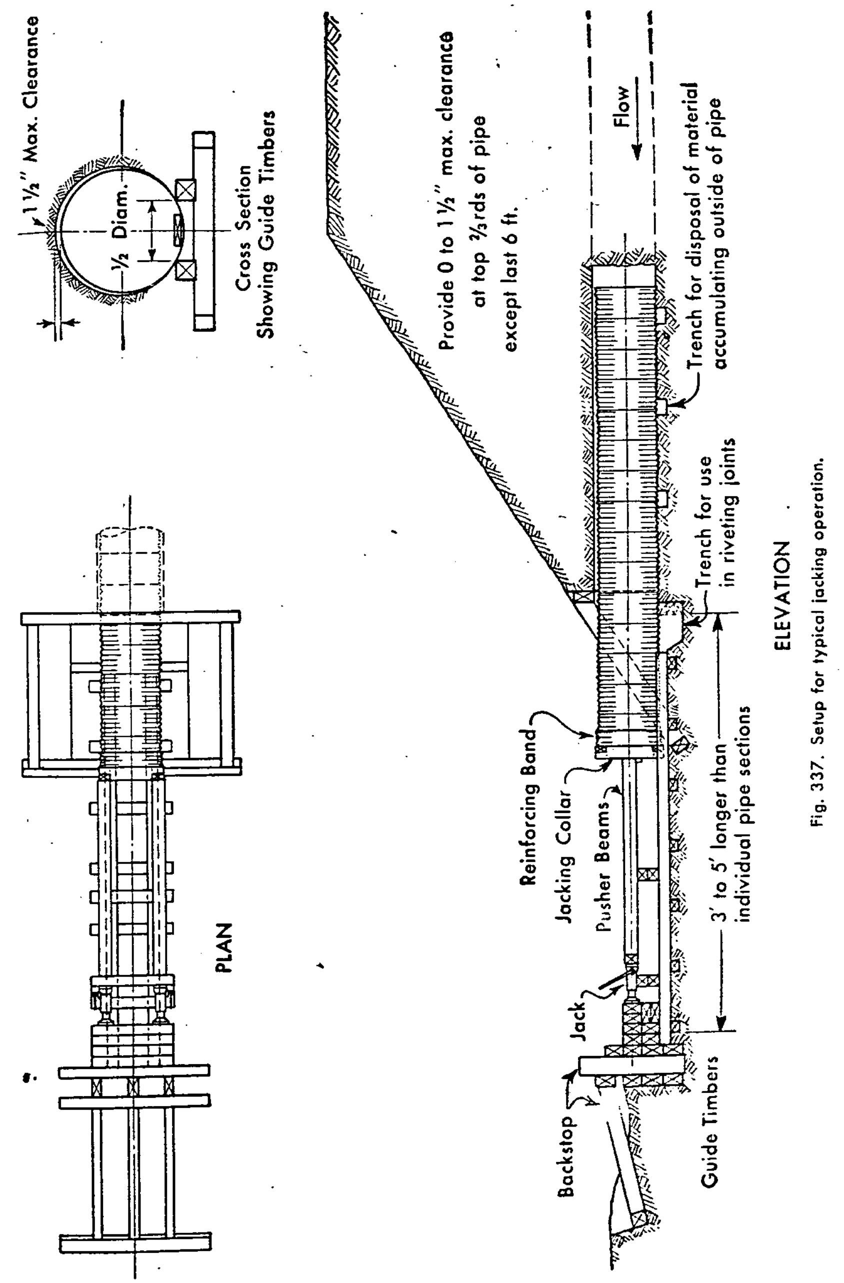

Fig. 337. Setup for typical jacking operation.

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Fig. 338. Jacking 36-in. corrugated metal pipe under main line railroad.

to excavate an approach trench into the fill far enough to provide a jacking face of 3 ft or more above the pipe. This open face should be shored securely to prevent slipping or raveling of the embankment. Provision for a sump should be made in one corner of the approach trench or pit.

Backstop and Guides

A substantial backstop is necessary to take the thrust of the jack. A 60 to 80-ft length jacking job in reasonably good soil often develops 150 to 300 tons of jacking resistance.[2] The backstop is usually of heavy timbers.

The timbers or steel rails that support the pipe as it enters the bore must be accurately placed on line and grade. Both line and grade should be checked at least once per shift as the work progresses. Fig. 337.

Pipe for Jacking

For corrugated pipe to be jacked, the sections are especially prepared for making field joints by riveting or bolting. The use of a jacking band to reinforce the end receiving the thrust is recommended especially for long lines or large diameters. When jacking through loose or gravelly soils, smooth steel sheets of light gage should be bolted to the top and bottom of the pipe sections.

Equipment

Necessary equipment for jacking includes an electric power plant for lights, pumps, excavating tools, muck handling equipment and jacks. Often an air compressor for air spades and breakers is justified. A wheel-barrow is economical for pipe 48 in. and larger. For smaller pipe, some type of skip or dolly-mounted dirt box is required.

Any of several types of jacks can be used. These should have a capacity of at least 35 tons and be operated in pairs. Travel of jacks should be at least 13 in. Small track jacks can be used to start the pipe. Fig. 338.

Working Crew

A crew of four men and a sub-foreman, per shift, provides the necessary manpower. However, during the preliminary work of excavating the working pit and placing the backstop, more men can be employed, such as by combining two shifts.

One man digs at the head of the pipe. A second man loads the dirt buggy. The other two remove the excavated material and they jack the pipe. All hands join in lowering a section of pipe into the trench and making the field connection.

Jacking Operation

As material is excavated ahead of the pipe, the pipe is jacked in to follow this excavation. The distance dug ahead of the pipe rarely exceeds 12 to 18 in. Some loose soils may reduce this to 3 or 4 in.

Excavation should be about 1 in. more than the outside diameter of the pipe at the top, and taper off towards the invert.

REFERENCES

1. For details see "Jacking Culverts Through Fills," by C. M. Colvin, in *Western Construction*, San Francisco, April 1953.
2. Where excavation is carried ahead of pipe, the pressure may be 125 psf of surface area of imbedded pipe. Where jacking is progressed ahead of the excavation, the pressure may be 600 psf, according to Jacob Feld in Bull. No. 14, Highway Research Board, 1948.

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Fig. 339. Another method of installing small conduits under streets and railroads is by boring.

CHAPTER FIFTY-FIVE

Boring

BORING is another means of installing conduits and culverts without disturbing surface structures or traffic. This method is generally confined to pipe diameters from 1 in. to 36 in. Various types of machines on the market are built to perform this operation.

There are two basic methods for accomplishing the objective, the first of which is to push the conduit pipe into the fill as the boring auger drills out the ground. Fig. 339. The second one consists of drilling the hole through the fill and pushing the conduit pipe into the hole after the drill auger has completed the bore. Both of these methods have their advantages, but if there is any doubt concerning the ground conditions, the first method is the safer of the two and offers greater protection to the surface structure under which the conduit is being placed.

For example, if the second method is used and a sand pocket is encountered in what is otherwise a good stable fill, it is easy to imagine that a void in the fill could be created that would cause a lot of trouble. The use of boring equipment for installing small diameter tubing is illustrated on page 358.

Location of Holes

Since these boring installations are generally of small diameters, the possibility of being stopped by encountering boulders, rocks or utility lines should be taken into consideration and alternate locations for the conduit should be provided. In some locations, rocks and boulders are prevalent, while in other areas the possibility of encountering such obstacles is remote. Hence the engineer and the contractor must guide their thinking accordingly. Where obstacles are encountered in fills, it may be necessary to abandon that exact location. However, by starting a new hole at a distance of as little as 1 foot either side may make it possible to miss the obstacle and go through with a successful installation.

There have been cases where as many as six holes were drilled before a clear path was found for the boring tool.

There are machines that will bore through rock and coal, but sometimes it is not economically practical to adapt these rock cutters to earth augers. Most boring augers will penetrate soft rock, wood or brick, but experience and "feel" are required to judge the practicability of going ahead when such obstacles are encountered. Line and grade may suffer because of these obstacles and even though it is possible to complete the bore, it may not be satisfactory for the purpose intended. Under such circumstances it may be wiser to abandon the bore when the obstacle is encountered and move a few feet to try again for a clear pathway.

The horizontal boring method of installation is not an exact science and hence requires experienced personnel, good investigation of ground conditions, good equipment and flexibility of thinking.

Instructions

Detailed instructions are not available. However, in general, the information given in the preceding chapter on Jacking applies here.

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No 18

Rotary-Percussive Drill Studies Explain New Drilling Technique

E. W. INETT, PH.D.

NEARLY ALL present day rock drilling is accomplished by one of two methods—percussive or rotary. Until comparatively recently, the percussive system was confined almost exclusively to "hard" rock and the rotary to coal and other "softer" strata. Extensive research into both methods has led to a full understanding of the mechanism of each and consequently has widened the spheres of application of each system. However, such research has also led to an appreciation of the limitations of the respective systems. In short, neither system has the capacity to drill hard rock types at high penetration rates without the provision of high power-inputs, high applied thrusts and considerable cutting edge wear. More particularly this latter aspect has led to the failure of rotary drilling in hard rock.

A study of main conclusions drawn from investigations in pure rotary and pure percussive drilling reveals many common factors — especially limitations. It is possible to show that a combination of the two systems in the form of a continuous rotary motion with percussion superimposed offers the best of both systems and eliminates many of the common limitations. Thus rotary-percussive drilling will enable the harder carboniferous strata to be drilled at rates comparable with those already achieved by rotary methods in the softer carboniferous sandstones.

To appreciate the design and principle underlying the combined system, it is first necessary to refer to limitations of existing percussive and rotary systems.

Percussive Drilling

Design of the percussive drill is well known; chuck rotation is integral with piston travel. The rotation mechanism is a ratchet and twist bar so designed that the piston has a straight forward-travel during the working stroke. Immediately the return stroke begins, pawls engage and the piston must rotate as it moves back. Rotary motion of the piston is transmitted by splines (in its forward end) to the chuck and thence to the drill steel.

Any drill operator realizes that to obtain maximum penetration rate at a given air pressure he must maintain a balance between the recoil at impact and the degree of thrust he applies to the drill. This is well illustrated by Fig. 1 (Cheetham and Inett, 1953) which shows the variation of penetration rate with applied thrust, air pressure being constant. This curve is divided into three sections, each representing conditions defined by the thrust applied.

Thrust is Prime Factor

Low thrusts give rise to low penetration rates, and there is excessive "chatter" of the drill and steel. Thus the over-all contact time between the cutting edges and the rock face is extremely short. More blows may be delivered to the steel while it is out of contact with the rock than when it is actually in contact and doing useful work. Furthermore rotational speeds are high and the angular distance travelled by the bit in penetrating any given distance into the rock is considerable. In consequence the cutting edges are subjec[illegible] to severe abrasive wear and there is excessive gage loss.

Medium or balanced thrusts lead to maximum penetration rates. Drill steel chatter has been reduced and the cutting edges are in contact with the rock face when every blow is delivered. Thus maximum benefit is obtained from each blow. Rotational speeds are lower, so reducing both abrasive wear and gage loss and permitting cutting edges to bite into the rock with a smaller angular displacement between successive blows.

Excessive thrusts ca[illegible] reduction in penetration rates. T[illegible] main effect of this phase is that rotation becomes increasingly difficult; rotation is soon eliminated and the drill stalls.

Cheetham and Inett indicate that the reasons for these phases are as follows. At any given air pressure, the *potential* energy output from the piston head is substantially constant. Under this condition, is it the applied thrust which is the controlling factor in determining the actual energy output and utilization of that energy. Among other factors energy output is dependent upon the impact velocity of the piston; in turn, this is dependent upon the nominal piston stroke. But the machine is not always operating at nominal stroke and the extent to which the stroke varies is dependent upon the applied thrust.

In all percussive drills, the nominal stroke is that executed by the piston before it strikes the shank, assuming that the shank is in the correct position to receive the blow. However, due to insufficient thrust, should the shank not be in the correct position when the blow is delivered, the piston will over-stroke in excess of the nominal stroke by an amount limited only by the degree of air cushioning and the position of the chuck rear face.

Cheetham and Inett show that increase in the applied thrust tends to reduce overstroking progressively until it is completely eliminated. Further increase in applied thrust will then reduce the nominal working stroke. This effect is readily explained. An increase in applied thrust increases the resistance to rotation since the rebound of the drill steel is limited and the contact between the bit and the rock exerts a resisting torque upon the rotation mechanism. Since at any one working pressure, the potential ability of the piston to effect rotation is limited, the return (or rotating) stroke of the piston is progressively reduced in length as this limited potential is more rapidly used to overcome the rotational resistance induced by increasing applied thrust. Thus a position is reached when the resistance to rotation is so high that the piston is unable to move and, in consequence, the machine stalls.

Independent Rotation Is Best

In essence, therefore, rotation must be maintained. Drill steel rotation can be shown to the sum total of two component parts, one being the rotation due to the inertia of the rotation parts

* This article is based upon a paper prepared by Dr. Inett for the Annual Drilling Symposium of the Department of Mines and Metallurgy, University of Minnesota, October 1955.

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Applied Thrust—Key to Drilling Speed

FIG. 1 HOW INSUFFICIENT THRUST AND EXCESSIVE THRUST AFFECT ROCK PENETRATION RATE

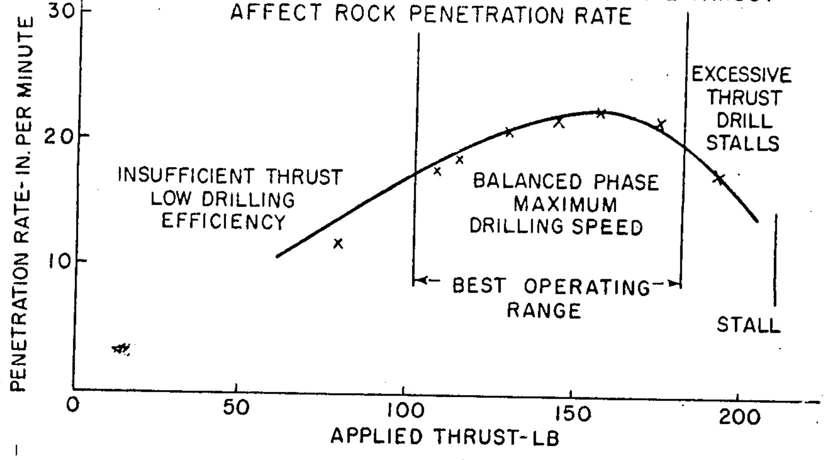


FIG. 2 HOW INCREASE IN APPLIED THRUST SLOWS DOWN ROTATION

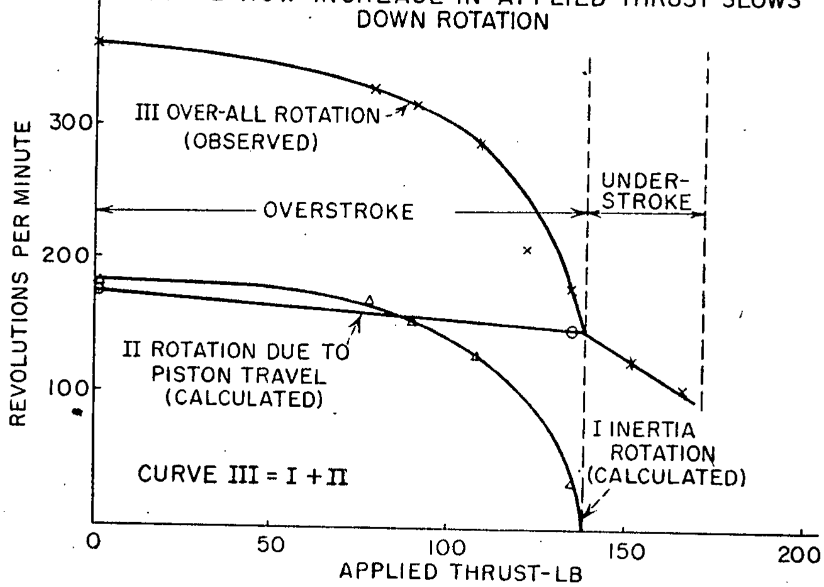
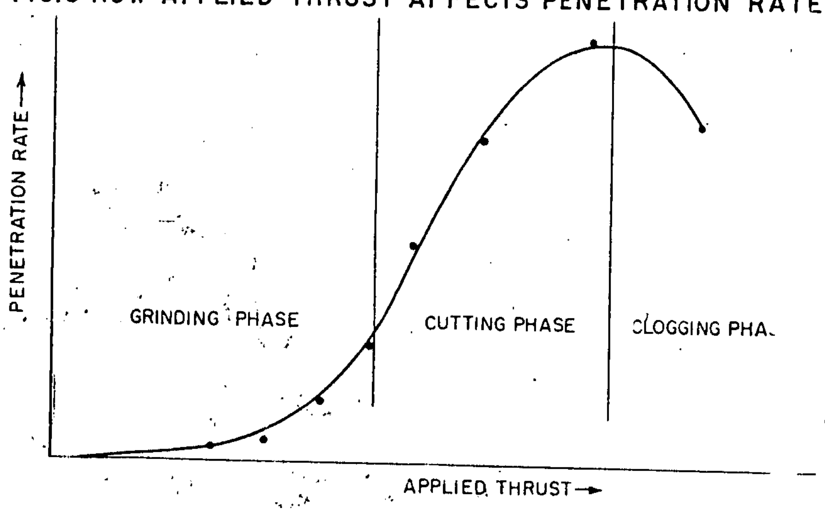


FIG.3 HOW APPLIED THRUST AFFECTS PENETRATION RATE



and the other being the rotation due to piston stroke alone. Fig 2 shows the effect of the applied thrust on the over-all assembly and each of the component rotations. It is certain that peak speeds are reached when the greater part of the inertia-rotation has been eliminated, i.e. there is just enough resilience in the system to enable rotation to be effected without the resisting torque affecting piston travel.

To summarize, Cheetham and Inett claim that . . . "If full working strokes and rigid positive control of rotation are to be achieved, then the mechanism producing rotation should not derive its energy from the piston and must not impede piston operation. These conditions can only be satisfied by a machine having independent and variable rotation. In a machine of this type each blow could, under satisfactory thrust conditions, contribute its full effect."

Rotary Drilling

The operation of a rotary drill is not nearly as complex as that of a percussive drill. A relatively high powered motor provides the necessary shearing force and the thrust, again externally applied, provides the pressure force necessary to keep the bit edges well up to the rock face.

As in percussive drilling, thrust is the all important factor governing penetration rate. This is clearly shown by Fig 3 and the shape of this curve appears to be characteristic of most rotary drill bits in Carboniferous sandstones and shales. Many workers have produced more or less the same curves which, (as in percussive drilling) lend themselves for division into three characteristic sections.

At low thrusts the penetration rate is low but improves at an increasing rate as more thrust is applied. During this phase, the cutting edges appear to be bouncing over the surface of the rock and, in consequence, should be avoided since it is inevitably accompanied by severe abrasive wear.

Medium thrusts lead to a considerable improvement in both penetration rate and bit wear. Obviously this phase is the ideal working phase.

At higher thrust, the performance deteriorates and a thrust is reached beyond which the penetration rate actually decreases. Further increase in thrust stalls the drill. This condition should be avoided and is due almost entirely to the accumulation of cuttings at the bit tips increasing the resisting torque to unsurmountable levels. Thus a rotary drill will stall at high thrusts for very different reasons to those associated with percussive

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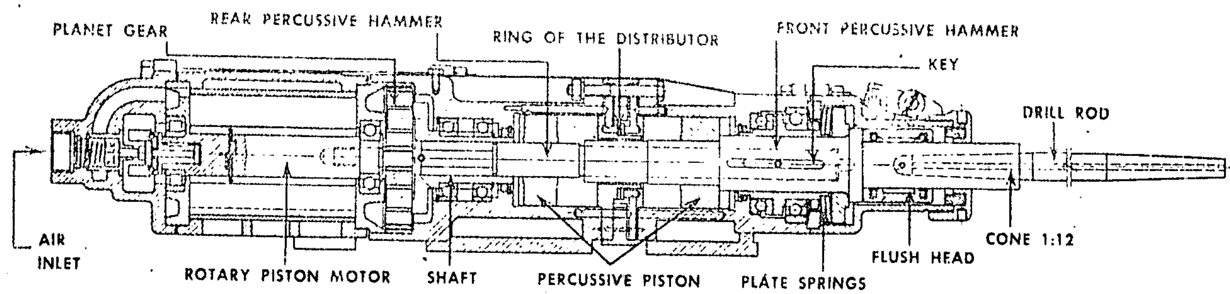
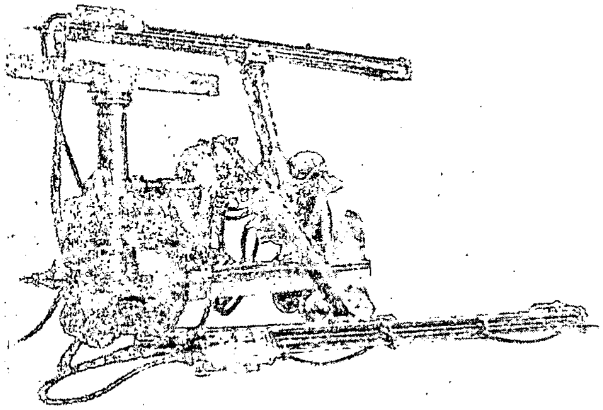
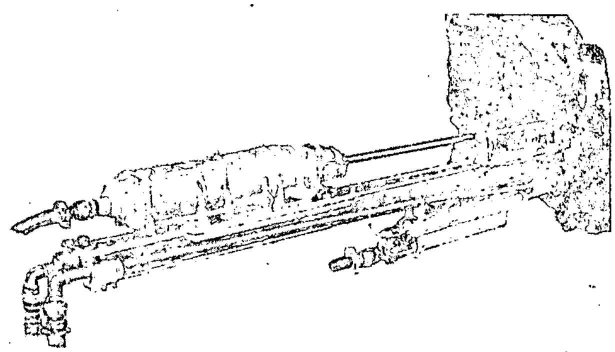


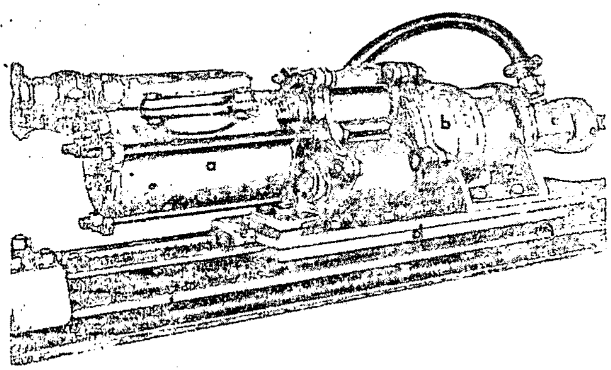
NEW ROTARY PERCUSSIVE DRILL is reported to drill about five times as fast as 45-lb percussive hammer drill. Drill is made by Hausherr in Germany. Unit delivers 6,000 blows per min at 180 to 200 rpm. Weight, 255 lb.



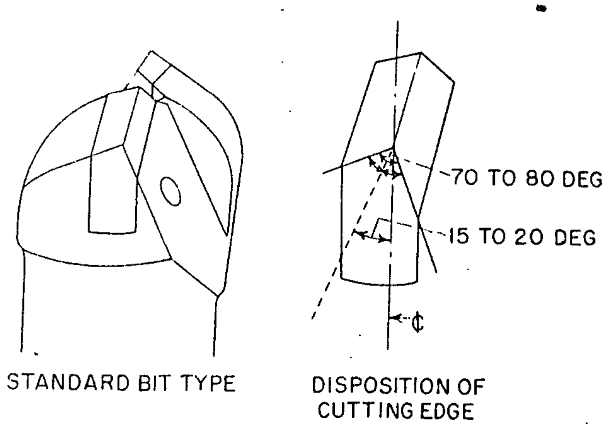
DRILLS on this jumbo develop ¾ to 1½-ton screw-feed pressure. Photo, courtesy Nykerk Corp., New York, N. Y.



EXTERIOR VIEW of the Hausherr drill shown above. Drill will use either air or water flush. Courtesy Nykerk Corp.



TYPICAL machine nomenclature and technical data on three machines is given in Table I p. 78; performance in Table II.



ROTARY PERCUSSIVE bits perform entirely new tasks, and design of cutting adge requires much careful study.

Rotary-Percussive Drilling Calls for New Design

Rotary-percussive drilling was tried in Great Britain as early as 1922, but successful development of the unit failed. Recently, German manufacturers devised successful machines in the Ruhr coalfields. Several hundred of the machines are now in use. Several designs of drills and jumbos are shown above. The problem of applying large thrusts, high rotating speeds, plus a percussive action call for ingenuity in designs of drills and jumbos.

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drilling—rotation rather than stroke.

National Coal Board workers have termed this latter phase the "clogging phase," and it occurs when drillings are produced so fast that it is difficult to depose them from the cutting edges. Winder and Withers claim that the accumulated cuttings surrounding the bit tend to carry some of the thrust applied to the bit when, in effect, the whole of the thrust is not applied to the cutting edges. The falling off in the penetration rate/applied thrust curve is attributed to this cause. Clogging also causes friction between the bit and the side of the hole, thus increasing the torque required to effect rotation; clogging will eventually in-

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FIG. 4 HOW ROTARY-PERCUSSIVE DRILLING COMPARES WITH ROTARY AND PERCUSSIVE DRILLING AT VARIOUS APPLIED THRUSTS

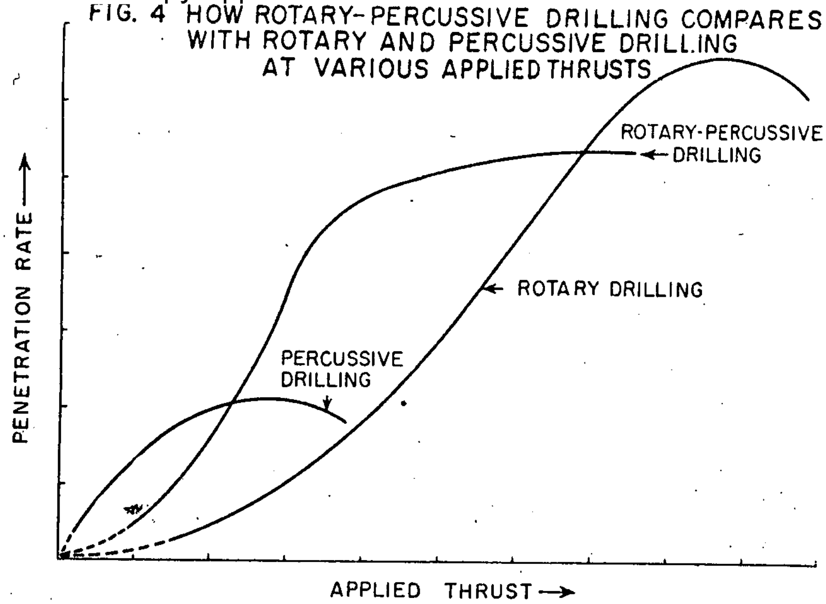

Table I. Nomenclature and Specifications

Machine	A	B	C
a* Piston chamber	Two pistons, each producing	One piston	One piston
a* Piston blow rate per min	2,500–3,000	3,400	3,400
Intensity of blow ft-lb	25	36	36
b* Compressed air motor hp	7	7	8
Rotation rate rpm	180	hard rock 100 medium rock 200 soft rock 350	180
c* External water feed			
d* Travelling base plate			
e* Power driven screw feed hp	3	2.5	—
Providing thrusts up to lb	3,000 (older model provided 7,500)	2,750	4,000
Usual thrust setting lb	1,250–2,500		1,700
Withdrawal rates ft per min	35	25–28	28
f* Airline feed motor			

*Letters match components shown in photo lower left p. 77.

Table II. Rotary-Percussive Drilling Summary of Drilling Details (Inett 1954)

Machine	Rock type	Holes per drill	Feet per drill	Over-all drilling time min	Drilling speed over cycle in. per min	Actual drill time min	Actual penetration rate in. per min
A.	Very hard sandstone	48	396	200	24	104	46
A.	Sandstone	40	330	150	26	70	57
B.	Very hard sandstone	40	330	180	22	100	40
C.	Very hard sandstone	25	208	120	21	70	36

Table III. Comparison of Maximum Speeds Observed in Varying Rock Types

Rock type	Drilling system	Drilling speed over cycle in. per min	Actual penetration rate in. per min
Sandshale	Percussive (airleg)	7.3	11.0
	Rotary	20.8	60.0
	Rotary-percussive	—	—
Sandstone	Percussive (airleg)	4.9	6.1
	Rotary	—	—
	Rotary-percussive	26.4	57.0
Very hard sandstone	Percussive (airleg)	—	—
	Rotary	13.2	20.6
	Rotary-percussive	24.0	46.1

duce stalling conditions. Of course, higher powered rotary mechanisms can resist the clogging stages for longer periods, i.e. can work at higher thrusts, than lighter machines.

At first sight, it would appear that the limitations of rotary drilling could be overcome by the application of a higher powered rotary motor combined with a higher flushing capacity for clearing debris. Unfortunately the problem is not as clear cut as this for there is the serious question of bit wear which is associated with high (and low) penetration rates. The wear is many times greater than that experienced with percussive drilling and induces a very rapid deterioration of penetration rate over comparatively small lengths of hole.

This edge deterioration results in increased difficulty in drilling and is severe at both low and high values of penetration per revolution. In the first case it is predominantly abrasive, i.e. the forces involved are small but the distance travelled in contact with the rock is large. At high penetrations per revolution the deterioration is due to overloading of the cutting edges, especially in the harder rocks, and takes the form of impact fractures (chipping). In the harder rocks to which rotary drilling has been more specifically applied of late, even the thrusts in the so called "ideal range" have been sufficient to cause chipping.

Rotary-Percussive Drilling

It is now clear that the applied thrust is the dominant control characteristic with regard to high drilling efficiency. At the instant of impact in percussive drilling, it is not a significant aid to penetration but rather is a method of ensuring the maximum transfer of energy from the piston head to the drill steel. In the pure rotary method the thrust is a means of ensuring that the bit edges do the job of shearing the rock away. In the new system the applied thrust satisfies both these conditions and, as such, is claimed to inherit many of the respective advantages.

Thus rotary-percussive drilling can be described as percussive drilling in which the bit is continuously rotated against the rock face under the influence of a high thrust; or alternatively as rotary drilling where the high thrusts so necessary for high penetration rates are obtained by the frequent application of impulses. Whichever of these two descriptions appeals most, the effect is the same and the drilling action is such that there is not only the indentation in the rock caused by the percussive action, but also the mark

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of the subsequent rotary cutting action.

The thrust application is critical and, indeed, must be limited to the most favorable level which varies with rock type. The thrust must be sufficiently high to prevent free and spasmodic displacement of the drill bit (phase I—percussive drilling) but it must not be so great that it maintains the edges in the indentation produced by the impulse. The thrust must permit the cutting edges to slide out of the indentation of each blow. Thus thrust levels need not reach the heights characteristic of rotary drilling.

Such is the principle behind the German combined percussive and rotary drilling system. It is not new; it was used in Great Britain as long ago as 1922 but was not developed because of contemporary technical difficulties. Figure 4 compares the penetration rate-applied thrust relationships of the three systems.

At the present time there are at least three German firms with well-tried products on the market and there are over 200 machines currently in use in the Ruhr coalfield alone. See illustration lower left page 77 for a model which is typical of the design of these machines. Principal components are lettered and named in Table I p. 78.

To some extent these drill designs have overcome many of the limitations of conventional drill types. It has been shown that the follow-factors are inherent advantages of rotary-percussive drilling rather than very significant limitations of the individual systems.

Advantages of R-P

1. Rotation is not tied to piston travel; it is provided by a separately powered unit.
2. Piston stroke can be fixed with the knowledge that each blow will be delivered from full stroke. Blow energies can be accurately rated.
3. The drill steel is always in he correct position to receive the blow since the shank will always be in contact with the chuck face.
4. A highly rated rotary mechanism is available providing a readily adjustable range of rotation values.
5. A motor distinct from the rotary motor provides the high thrusts so necessary for high penetration rates.
6. Due to the cutting action, the thrusts peculiar to the combined system must not be as high as those of the rotary system alone; bit wear is reduced.

However, it is obvious from the very different standards set by each of specified machines that there are still many unknown quantities in rotary-percussion drilling. Such factors as strength of blow, frequency of blow in relation to rotational speed, thrust, etc., are currently receiving attention both in Great Britain and in Germany. For the moment "clogging" has disappeared from the scene, but it is almost certain that it will again become apparent as very high penetration rates are attained.

The manufacturers of the drill illustrated lower left, p. 78 claim drilling speeds of up to 35 in. per minute in granite, 47 in. per minute in hard sandstone, 67 in. per minute in medium hard sandstone and 86 in. per minute in sandy shale. The accompanying tables represent summaries of data collected in the Ruhr coalfield. Table II shows the penetration rates actually achieved by the rotary-percussive drills under working conditions and Table III compares the system with conventional drilling methods in varying rock types.

It is to be expected that even more striking differences will be attained as and when a proper understanding of the previously mentioned factors is achieved.

Drill Steel and Bits

Some brief word is necessary regarding the associated drill steels and bits. Experience has shown that an anvil block located between the piston and the steel (the anvil block usually passes through the air motor and transmits the rotary motion to the steel) enables the drill steels to last almost indefinitely. (Otto and Kinna, 1953, suggest 10,000 meters as an average figure.) However, a 10-15% reduction in penetration rate can be expected. Direct impact between the piston and the drill steel is said to reduce the drilling life of steels from the quoted average of 10,000 meters to 600 meters only.

The bits used with the initial rotary-percusive machines were conventional rotary bits, but, as might be expected, they were not generally satisfactory—they were too weak. However, while bits in current use are still similar in appearance to rotary bits, in design they are really a compromise between both rotary and percussive bits. Figure p. 77 shows that they are of a more robust construction that rotary bits—indeed they must have the strength of percussive bits—and whilst they show a greater clearance space than conventional chisel bits, they again have less clearance than rotary bits.

The actual disposition of the cutting edge has been the subject of much study. For instance, a percussive cutting edge is merely called upon to fracture segments of rock and drill design tries to ensure that at the moment of impact rotation is halted. A symmetrical wedge edge is considered adequate to do this. On the other hand, a rotary cutting edge is expected to shave a comparatively uniform depth of rock from the base of the hole, but it is not expected to fracture the rock by an instantaneous penetration. Thus at the instant of impact the rotary-percussive bit is known to penetrate rock at some angle between the perpendicular approach of the percussive bit and the horizontal attack of the rotary bit. During the period between blows, the bit must penetrate as a pure rotary bit. To facilitate these actions, the cutting edge is but 70 to 80 deg only and is set asymmetrically to the center line of the bit. The bisector of the cutting wedge forms an angle of 15 to 20 deg to the bit axis.

Although various bit shapes have been developed, that shown on page 78 represents the standard form of present day bits. It has proved itself a most reliable bit for use in all types of rock.

As with conventional bits, bit wear varies very considerably with rock type, general figures being about 30 ft per regrind in very hard sandstone, 80 ft per regrind in sandstone and about 300 to 350 ft in sandy shale. Whilst these figures represent a considerable increase in drilling life over rotary bits, they are very similar to percussive cutting figures. However, bit wear can be said to lie between the two extremes of rotary and percussive drilling, but with a tendency towards percussive drilling values in comparable rock types.

Acknowledgments

The author wishes to record his thanks to the Institution of Mining and Metallurgy and to the Institution of Mining Engineers for permission to reproduce certain illustrations and tabels.

Any opinions expressed are the author's and do not necessarily reflect any official viewpoints.

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No. 19

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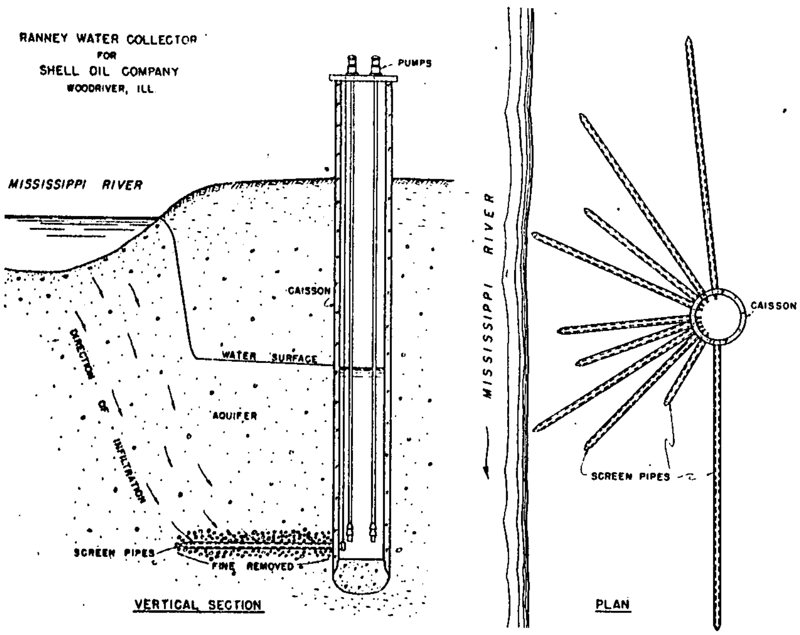

FIG. 1. Monolithic caisson sunk 110 ft in Mississippi River bank and actual plan of radial screen pipes at Shell refinery.

Shell Water Well to Produce 10,000,000 GPD

Vast underground reservoir tapped by one new-type unit to replace half of present vertical wells

EUGENE B. BRIEN*

FOR the first time last month, Shell Oil Company tapped for its refinery use at Wood River, Illinois, the huge underground water reservoir provided by nature from infiltrated waters of the Mississippi River. Tapping a practically unlimited reserve of water, one new, radial type well will produce a minimum perennial guarantee of 10,000,000 gal per day, a supply sufficiently large to meet a large portion of the needs of the enlarged 170,000 bbl per day plant. This daily production, equal in volume to a tank 200 ft in diameter and 43 ft high, promises in time to render obsolete about 15-20 ordinary wells the company has been using in the past, it reports.

Treating Costs Too High

A major expansion of refining capacity at Wood River required the company to extend its source of water supply for steam generation and for makeup to cooling towers beyond the capacity of existing wells on the refinery property. Overall chemical costs for treating water from the old wells had increased to a figure in the order of one quarter million dollars per year, while the hardness of the ground water had more than doubled during the last 18 years.

Shell therefore decided to seek a reliable additional source of softer water, and, in view of the proximity to the Mississippi River, to investigate the horizontal type of underground water collector well developed by Ranney Method Water Supplies, Inc., of Columbus, Ohio. Economic studies indicated that costs for treating surface water taken directly from the Mississippi River would be greater than for ground water drawn indirectly from the subsoil of the river bank.

Test drillings by the radial well company along the Mississippi River at Hartford, Illinois, two miles from the site of the refinery, confirmed that the volume of water infiltration from the river bed into the large underground water-bearing formation, locally known as the American bottoms area, could be relied upon to meet the additional estimated needs of the refinery. An ordinary vertical well sunk into the same formation would tap only the immediate vicinity of the well, a relatively small area. Sinking the "waterwheel" type of well (Fig. 1) would permit draining a thousand feet or more of the water-bearing formation, possibly the equivalent of 10 or more vertical wells.

Developed in experimenting for the recovery of residual oil from sand and shale in the 1930's, the waterwheel well has two integral parts: A large, concrete vertical shaft sunk in an aquifer (a waterbearing formation); and hundreds of feet of slotted screen collecting pipes projecting from the shaft radially and horizontally at certain levels in the aquifer. The Shell refinery well at Hartford has a shaft with an inside diameter of 13 ft resting on bedrock 110 ft below ground and ten 8 in. diameter horizontal laterals, projected approximately 1300 linear feet in a fan-shape pattern in the formation. This equipment has a design capacity of 10,000,000 gal per day.

Well Construction

Construction of the well and the accompanying waterheader to the refinery 11,000 ft away began during the winter of 1952 and was completed recently. The central collector, a monolithic shaft or caisson almost 140 ft long with an 18-in. reinforced concrete wall, projects some 30 ft above ground level in order to be above the top of the inland levee and consequently above the highest recorded flood water mark. Atop the caisson, the electrical equipment controls and pump motors are installed without any special housing other than their own weatherproof casings.

The caisson was constructed in 11-ft 6 in. sections on the site selected for the well approximately 100 ft from the east bank of the Mississippi. The reinforced concrete of the first section was poured in removable steel forms and fitted with a steel shoe that was to act as a cutting edge for the sinking of the shaft. After the steel forms were removed, a ¾ yd clamshell bucket digging machine began excavating from inside the shaft. As the digging progressed, the 118,000 lb weight of the section gradually sank it into the ground. (Fig. 2.)

A second section was poured similarly into forms and made an integral

*Eastern Editor.

EXCLUSIVE

Reprinted from THE PETROLEUM ENGINEER, March, 1954

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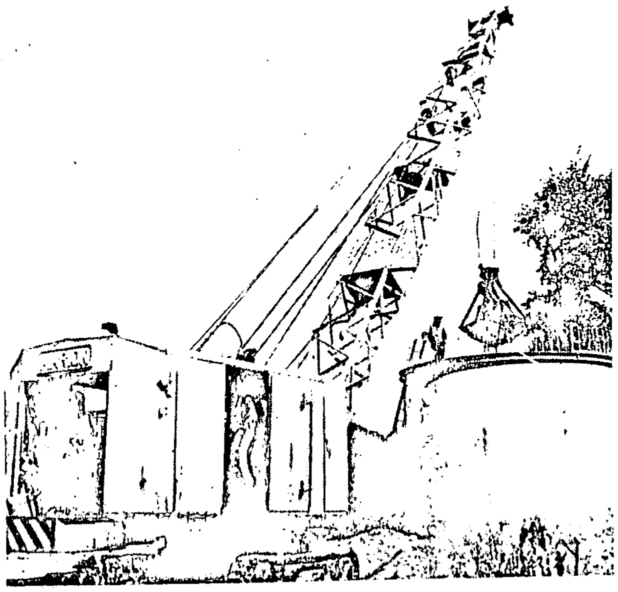

FIG. 2. Caisson, excavated from inside by clam-shell, sinks of its own weight.

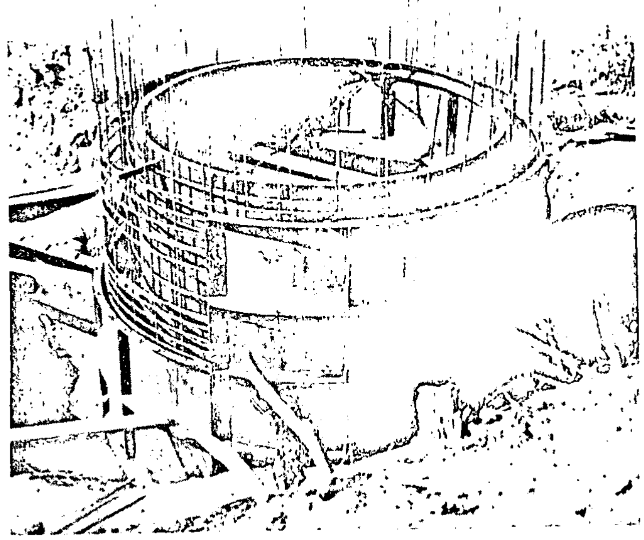

FIG. 3. Cast in 12-ft sections, caisson is made into a monolith with an 18 in. thick wall.

part of the lower section. When the concrete was cured sufficiently in this section, the forms were removed and the clamming was continued. The combined sections sank of their own weight. The process was repeated until the caisson rested on bedrock 110 ft below ground level. One 11-ft 6-in. section was constructed every third day; the entire underground portion of the shaft was installed in approximately one month. In sinking, lateral drift of the shaft proved negligible: E-W drift was held to a small fraction of a foot; N-S drift amounted to 9-in. (Fig. 3.)

To anchor the caisson firmly and to prevent water and other materials from entering through the bottom, a tremie-poured, reinforced concrete plug was added to seal the bottom.

Radial Collector Screen Pipes

When the bottommost section of the caisson was constructed, 24, 10-in. portholes were precast in the shaft wall. (Depending upon the nature of the water-bearing formation, any other section could have been provided with as many as 36 portholes.) Before the caisson was sunk, the inner ends of the portholes were fitted with blank plates and ring gaskets to protect the plugs from being crushed or cracked by pressure as they descended into the ground.

Ten of the portholes were fitted with flanged, cast-iron gate valves through which the collector screen pipes were to be projected.

After the well bottom was sealed and dried of water, collector screen pipes in 8-ft lengths were taken down and forced radially from the shaft through the portholes with two 150-ton hydraulic jacks. (Fig. 4.)

The first sections of each collector pipe had welded to them a special boring-head, a hollow, cast-steel conical digging-point with slots in its walls. A removable inner sand pipe opening onto the slots and extending from the digging-point, through the length of the screen pipe and the jack frame, and into the caisson, allowed the sand and water to flow directly to the bottom of the shaft as the pipe was projected into the formation.

In addition to removing some sand from the aquifer, the air and water action in the sand pipe created a reverse jet action to losen the formation ahead of the digging-point. Along with this jet action, pressure from the nearly 100 ft of water head in the formation helped clear an assumed radius of several feet of silt and sand around each collector pipe. Periodically, the formation was loosened by a reverse flow of compressed air, increasing the

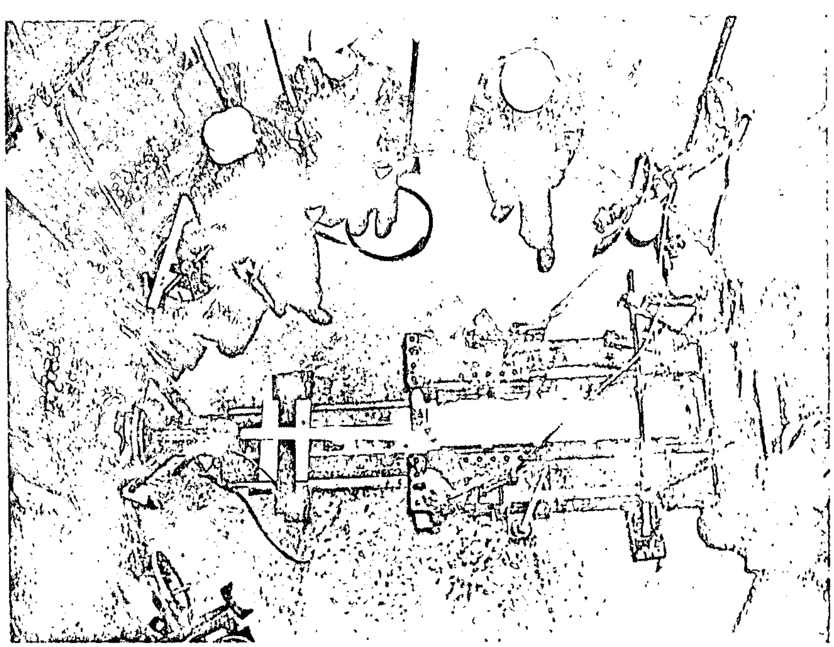

FIG. 4. Hydraulic jacks forcing slotted screen pipe at left through caisson wall into water bearing formation.

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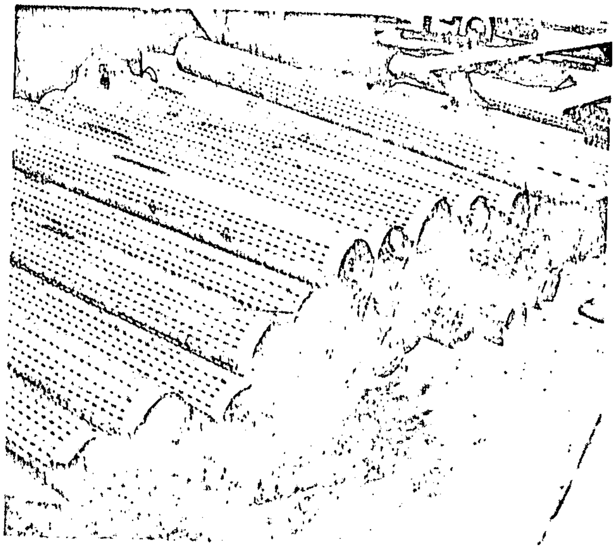

FIG. 5. Slotted screen pipes with welded boring head waiting to be projected through caisson walls into aquifer.

FIG. 6. Individually controlled portholes permit flushing each lateral to remove silt and sand.

effectiveness of the flushing action. A coarse layer of gravel remained around each of the screen pipes to act as a natural gravel filter and to increase considerably the capacity of the collecting pipes. The amount of sand that was removed averaged about 3 cu ft per linear foot of pipe projected.

A special arrangement of rubber packers around the outside surfaces of the pipes at the portholes and a specially constructed sliding hydraulic packer built on the inside to withstand water pressure and sand abrasion, prevented water and sand around the outer surfaces of the pipes from gushing into the caisson.

After all but a small part of each section of the collector pipe had been forced outward from the caisson, another 8-ft length of pipe was welded to the preceding section. This process was repeated regularly until the pipe had reached the desired horizontal distance, or possibly until it had encountered a large underground boulder and could not be forced outward any farther. The maximum extension of any pipe in this well was about 200 ft.

After all laterals — 10 in all — had been pushed out in this manner, the total length of water-collecting pipe amounted to 1306 linear feet. The total area in the pipe open to the flow of water amounted to over 500 sq ft. Water velocity through the screen openings when the three pumps are operating at design capacity is about 0.03 ft per second.

The screen pipes were made from 8-ft lengths of 3/8-in. copperbearing steel plates. Punched flat with 1½ in. by 1.4 in. slots, two plates were formed into semi-circles and welded together to form a pipe with an 8-in. inside diameter. For each linear foot of pipe there is 0.38 sq ft of openings. The ends of the lengths are beveled to permit easy welding to succeeding sections. (Fig. 5.)

After the predetermined footage of well screens had been pushed out, all portholes were closed by their gate valves and the pipes were then flushed individually until no sand flowed in with the water.

Pumping Equipment

The installation has three, 2500 gpm deep-well, vertical, 4160-v motor-driven pumps; a position is provided for a fourth pump if and when it should be needed. Pumps are placed about 100 ft below ground level and have a suction head varying, in accordance with the rise and fall of the river, from about 10 to 40 ft of water. The combined capacity of the three pumps at minimum suction head condition is 10 million gallons per day with water delivered into the central refining area, two miles away, against a pressure of 50 psi gage pressure in the refinery main distributing headers.

Motors for the pumps are situated atop the shaft. The initial average draw-down of water in the caisson is estimated to be 7 ft when pumping proceeds at the design capacity of nearly 7500 gpm.

Gate valves at each porthole control flow of water through the individual lateral pipes. Any or all valves may be opened or closed at will by means of stems extending from the portholes to the concrete slab supporting the motors and switch gear. (Fig. 6.)

To carry the water from the well to the refinery two miles away, a 20 in. (inside diameter) header was constructed and buried about 3 ft underground. This water line, of pre-stressed design and construction, has a 16 GA steel core, wrapped externally with No. 6 gage wire under tension and lined both inside and outside with concrete 2 in. thick (¾-in. inside and 1¼ in. outside).

Water Characteristics

Chemical characteristics of the water to be obtained from this well are expected to be substantially equal to clarified surface water, according to the builder. The thick layers of sand and gravel through which the water must travel before reaching the collector pipes should remove substantially all sedimentation and suspended solids. The water should be fairly clear, have a low dissolved iron content, and an average year-round temperature of about 60 F. Prolonged periods of high or low river-temperature are reflected 2 to 3 months later in the well. During the summer, it is expected that water in the well may be as much as 18 F lower than river temperature, a decided advantage for cooling purposes. During the early winter, the water should be slightly warmer than river water.

As temperature has an important effect upon the minimum productive capacity of a well, the 10,000,000 gal per day guarantee was based on the lowest average river temperature expected to prevail over any 1 to 2 month period. As a consequence, normal average capacity may be considerably higher during the warmer seasons.

Installation Advantages

Other economic advantages of the waterwheel are indicated by the manufacturer. Where a large supply of water is required, and a [illegible] aquifer can be used, the [illegible]

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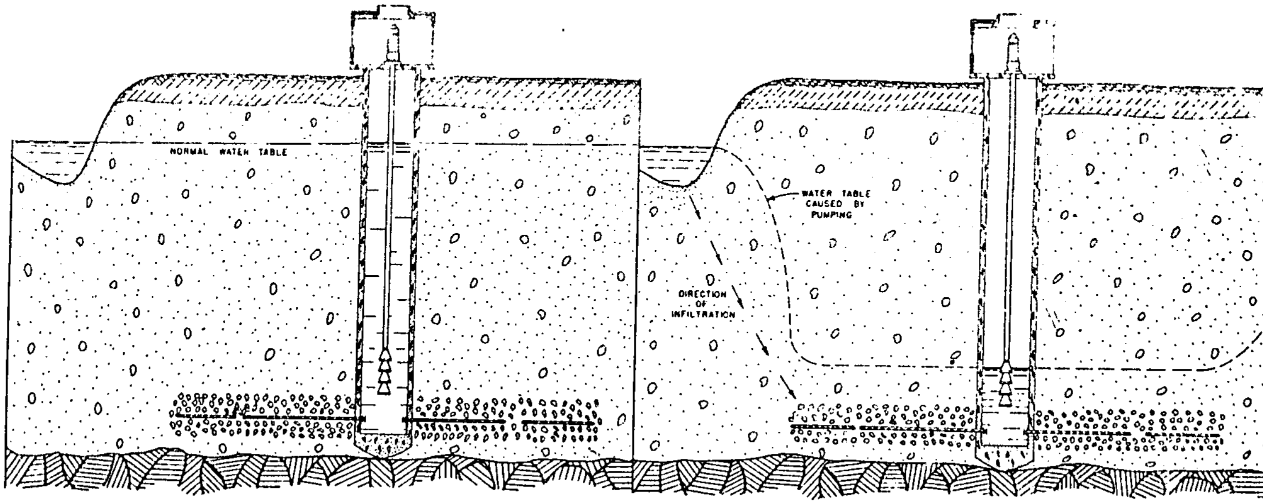

FIG. 7. Aquifers adjacent to rivers act as vast reservoirs that a.e continually replenished as their waters are pumped off.

fers one of the least expensive installations in terms of actual construction cost, maintenance, and service life.

The present installation, including the two-mile water header, cost somewhat over $625,000. The well alone cost about $250,000.

The large diameter (13 ft inside) of the central shaft permits the use of larger and more efficient pumps, pump .isers, and motors. Reportedly, pump efficiencies of 85 per cent and electric motor efficiencies of 93 per cent are standard.

The large shaft also permits easy access to the interior to facilitate repairs. Additional or new screen pipes may be pushed through extra portholes in the caisson without interrupting service of the whole installation for any extended time.

Even in high floods, all operating machinery is protected from raw water entry by the monolithic structure. Instead of promising destruction, floods should increase the effective suction head and consequently should enhance the productive capacity of the well, the builder states. Being a self-contained unit, the collector operates as long as power is supplied. In this case, a dual power supply at high voltage has been provided.

The large area of screen exposed — over 1/3 sq ft for each linear foot — permits low infiltration velocities through the screen openings. The extension of the collector pipes far beyond the central shaft helps reduce the approach velocity of the water through the water-bearing formation.

One direct result that assures longer service life, the builder reports, is the low pressure drop between water in the .ipe and in the nearby ground during normal pumping operations. With low pressure differentials, it is believed, no substantial liberation of dissolved carbonic gas, generally credited as the basic binder of alumina, silica, magnesium, and iron combinations that form incrustations, should take place. Another result of low pressure drop is the small loss of head: water-level in the shaft is but slightly lower than that in the ground, a fact said to be in striking difference with most other vertical wells as their age lengthens.

Geology of Aquifers

Other refiners plagued with water shortage or expensive water treating problems might well observe the general availability and functions of underground reservoirs. Practically all rivers or other bodies of water have adjacent to them permeable formations that hold vast quantities of water. For an understanding of the voluminous supply at hand in aquifers, one needs but to note that one acre of river bottom near Canton, Ohio, permits 3,600,000 gal per day to infiltrate to the water-bearing formation, as recorded in one section of the Nimishillen Creek by the Columbus Department of Public Works. At flood stages presumptive evidence of rates as high as 6,000,000 gal per day per acre have been recorded when water levels in the formation were sufficiently low to receive such a recharge.

To explain further the "why" of underground reservoirs, it may be desirable to describe briefly the occurrence and characteristics of this source of water. During glacial times, American rivers were many times larger than those existing today. When the glaciers began to melt, gushing torrents cut deep valleys over the face of the land. As the flow from the melting ice diminished in volume and velocity, deposits of clean gravels and sands filled the previously eroded valleys. Much reduced in size today, these same valleys channel our present rivers to the sea over the deposits of sand and gravel. (Fig. 7.)

Wherever deposits of this nature exist under bodies of water —assuming the absence of stagnant s.lt —they contain greater quantities of water than can normally be replaced by infiltration from the bottom of the stream or lake. The qualitative and quantitative supply of water obtainable from these formations can be accurately analyzed and predicted.

When large volumes of water are required, as in the range of 1,000,000 gal per day, they are best obtained from exposure of a large area of highly permeable aquifer parallel to a river. Small and even infiltration loads are placed on the river bottom and slow entrance velocities can be maintained in the collectors.

One pronounced difference between surface and underground reservoirs is that the latter do not remove productive land from cultivation. Storage capacity never decreases, so that the underground formation can supply peak loads even during periods of low flow in a stream. The surface of an infiltration area, the bottom of a river, seldom silts up, according to present records. The reason is that water moves along the river bottom in planes roughly perpendicular to the direction of infiltration. The fines do not remain on the surface of the infiltration as they do on regular filter beds, but are continually removed by the river flow and temporarily replaced by material coming downstream. River beds are constantly scoured and built up; no permanent layer of fine silt and organic matter has the chance to form. Consequently, the productive capacity of a formation fed by river infiltration may be expected to remain substantially constant. ★ ★ ★

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No. 20

Sinking Large Diameter Mine Shafts by Rotary Drilling

by Victor Zeni and Thomas N. Williamson

A 6-ft diam core drilling machine has successfully completed seven mine shafts in Virginia and West Virginia to depths as great as 465 ft. There is no practical depth limitation to this new system—a potential method in formations not easily penetrated with other large-scale drilling programs—and higher penetration rates and larger diameters are possible in some formations already being drilled successfully by other methods.

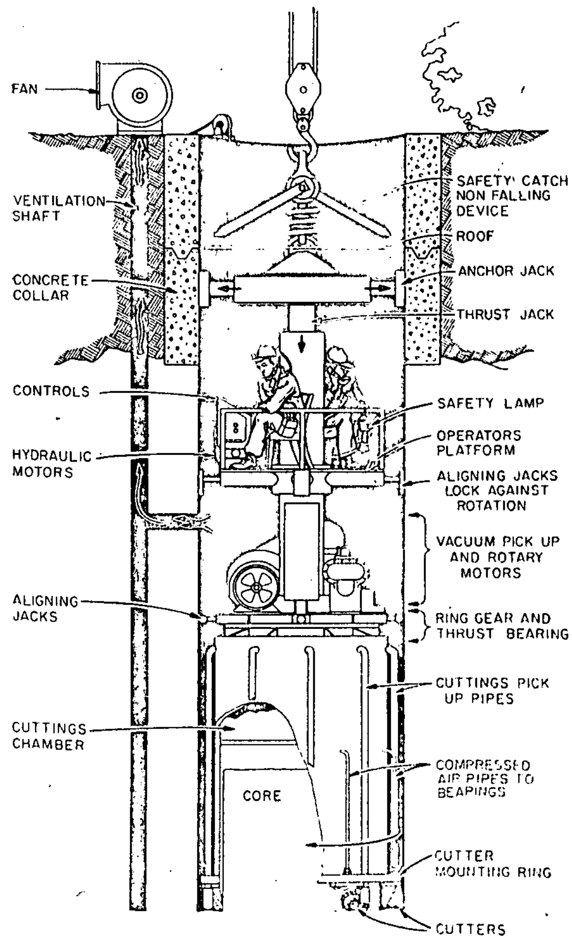
The core barrel on the machine is fitted with rolling cutters such as those used on oil field rotary bits, so that less torque is required than with other large-scale drilling systems. The core is made with a wider kerf than is achieved with other coring methods, providing more working room for core drilling.

Machine Development: In the early 1950's the Zeni Corp., a shaft sinking company, foresaw an expanded need in the mining industry for large-diameter drilled shafts to be used for portals, ventilation, or access. After studying conventional shaft drilling methods and other small-hole methods available, the corporation investigated the oil field rolling cutter.

This method of rock drilling was being accepted by the mining industry for blastholes in diameters from 4¼ to 12¼ in. The possibilities of coring or of drilling all of the bottom of the hole were both considered. Removal of the vast amount of cuttings, the need for tremendous thrust on the bit, and other considerations made it desirable to core. Special cutters would be required, since none were available to roll in these very large diameters or to cut a practical kerf width.

The drilling rig developers decided to build a machine that would go into the hole on a wire line. Since the rolling cutter drills by overcoming the compressive strength of the rock, the machine would be designed to apply a thrust of at least 100.-

VICTOR ZENI is with Coal State Construction Co., Morgantown, W. Va., and T. N. WILLIAMSON is with the Engineering Dept., Hughes Tool Co., Houston, Texas.



Zeni shaft sinking machine. Estimated cost of drilling machine and auxiliary equipment is $100,000. Drilling machine weighs about 25,000 lb. Drawing by W. L. Myers, Jr.

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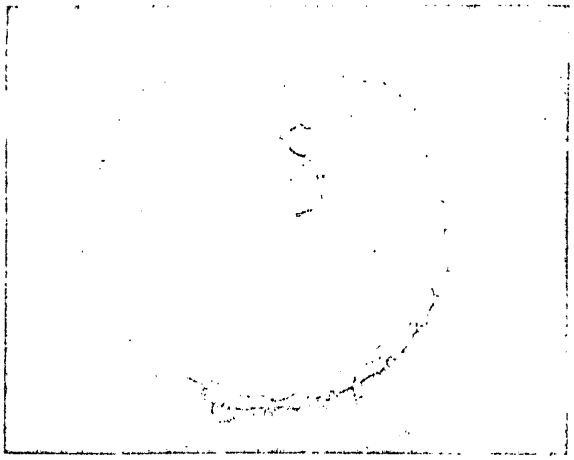
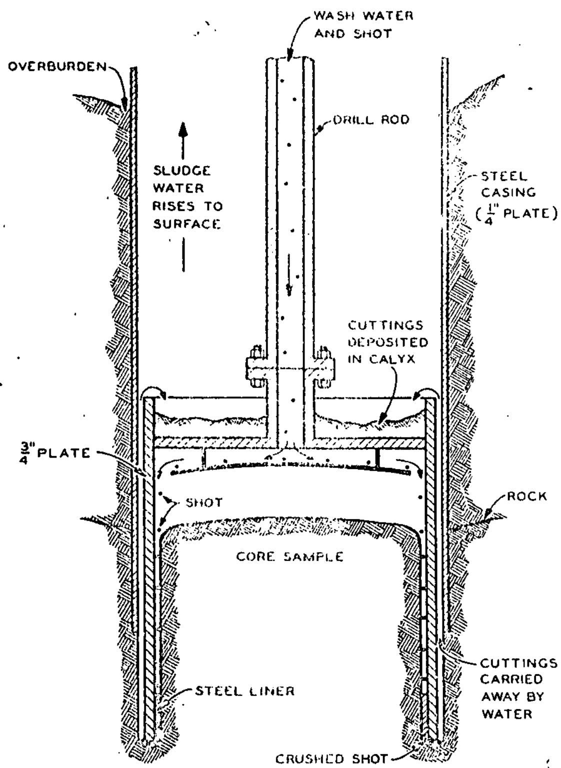


The machine is equipped to mount two sets of cutters with six in each set, but only one set of six is currently being used.



Calyx drill. Holes have been drilled as large as 5½ ft diam.

000 lb on the bits. It would be capable of rotating the core barrel at seven different rotary speeds between 0.9 and 15 rpm, as there was no prior experience to narrow this rpm range. Thrust was to be applied to the core barrel and bit by anchoring to the wall of the hole and using hydraulic pressure against this anchor.

At the beginning of this development it was believed that the volumes of air or mud required for positive or direct circulation would be prohibitive. To clean the kerf, in either wet or dry drilling conditions, vacuum equipment was incorporated in the design.

Cutter Development: After determining that a kerf 4 in. wide would be practical, Hughes Tool Co. engineers designed a cutter to roll in a 75-in. diam hole. This particular design will work satisfactorily in any diameter from 5 to 8 ft. Mounted on a conventional bit bearing of the tri-cone type, the cutters are bolted to a ring on the lower end of the core barrel. The angle of the bearing pin is such that as the bearing wears the cutter is forced out, compensating for gage wear. There has been no serious difficulty in getting back to bottom with a new set of cutters because of an undersize hole.

Before tests of equipment and method had begun at the Hughes laboratory, rig developers had started assembling parts for the machine. Design and development progressed concurrently with machine construction, with many improvisations for the sake of expediency. Trotter Coal Co., the first shaft customer, was very cooperative during this stage of development.

An accompanying sketch shows the principle of operation. A vertical thrust jack works against a horizontal anchor jack applying a load to bits on the rotating core barrel. Both jacks are hydraulically operated and are controlled from a central panel.

A 7½-hp industrial vacuum machine was used for cuttings removal. A 25-hp electric drive motor for the rotary and a 7½-hp motor for the hydraulic pump were provided. As no suitable hydraulic cylinder for applying thrust was readily available on the market, one was made from 16-in. casing in the Zeni shop. The 10-ft core barrel, of 70-in. diam, was fabricated from ½-in. plate. Steel angles were welded longitudinally for rigidity and strength. A cuttings chamber was made by installing a floor at about midlength inside the barrel.

A two-way swivel was designed and fabricated to permit simultaneous vacuum pick-up of cuttings and the passage of compressed air to the bearings for cleaning and cooling. A large ring gear and a thrust bearing were mounted on top of the barrel. A heavy duty truck transmission and differential were mounted between the electric drive motor and a vertical shaft with pinion, which engages the ring gear on the barrel.

The operator's platform, on which all controls are located, was placed just above the midpoint of the mechanism above the core barrel. Small mechanical screw jacks were installed horizontally at the top of the core barrel and at the operating platform level to assist in maintaining a straight hole and to help prevent rotation of that part of the machine above the core barrel. Owing to the plumb bob action of the machine these screw jacks have not often been needed for directing the hole.

The large horizontal anchor jack is at the top of the thrust jack. The hook on top of this anchor, by which the machine is lifted, is equipped with a spring-loaded mechanism that will grab the wall of the hole to prevent the machine from dropping should a wire rope break while it is going into or coming out of the hole. A round hinged roof with door on top of the anchor jack protects the men and machine from falling debris. So far there has been practically no spalling of the smooth shaft wall.

The machine is equipped to mount two sets of cutters with six in each set, but only one set of six is currently being used. Six cutters provide a sufficiently smooth operation and a higher unit loading on each cutter with the thrust available. Use of fewer than six cutters at one time is not recommended, as three of the six cut the inside half of the 4-in. kerf and three cut the outside. Each of the

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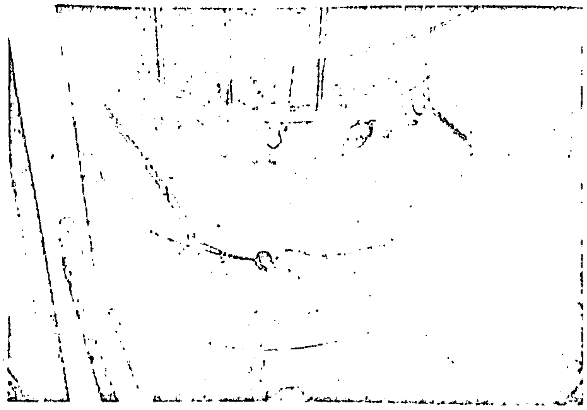
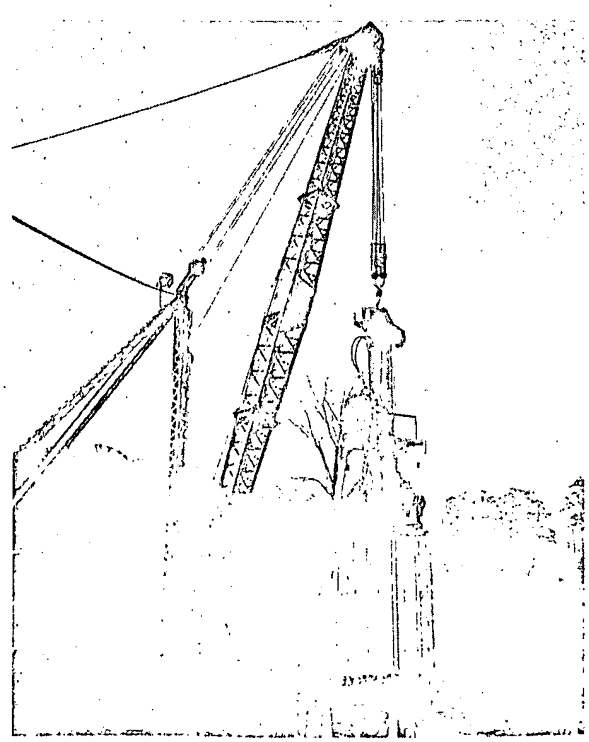


A core barrel for laboratory use was equipped with a two-way swivel to permit cuttings to be picked up with vacuum and air to be pumped to bearings to keep them clean and cool.



This 6-ft diam core drilling machine has successfully completed seven mine shafts in West Virginia to depths as great as 465 ft.

three cutters in each path has different numbers of teeth so that any rock gear formed by one cutter is broken up by the others.

A stiff leg derrick on the surface originally handled the equipment and core pulling chores satisfactorily but has recently been replaced by a truck crane.

Cost of the drilling machine and auxiliary equipment is estimated at approximately $100,000. The drilling machine alone weighs about 25,000 lb.

Starting the Hole: In starting a new hole, surface excavation is done by clamshell or other conventional means through the soft surface to bed rock or to a depth of about 30 ft, whichever is less. A 6-ft ID precast concrete shaft collar is inserted in this excavation. This heavily reinforced precast concrete pipe is in easily handled lengths which interlock.

Five to 10 shifts are required to move in the set-up and tear-down equipment for each shaft.

Water and Ventilation: Preliminary plans were to handle water, as it was contacted, by grouting through short jackhammer-drilled holes in the bottom of the shaft or through bulkheads in particularly troublesome areas. After the first shaft this plan was abandoned in favor of pregrouting the complete area through an 8-in. hole at high pressures. Short sections are plugged at a time, starting at the bottom. This grout finds its way into all crevices in the area of the shaft and stops all the main water flow in those areas where it has been used.

Since it is located just outside the proposed shaft circumference, the small grout hole is later redrilled and used for ventilation. A suction fan placed on top of this hole draws air down the shaft and up through the hole. The shaft sinkers tap into the adjoining hole at frequent intervals to keep air circulation close to the work. A 12-in. canvas blower sock originally provided for ventilation was thus replaced. Some of the seepage water is also removed as mist in the air drawn through this hole.

Water has been encountered in every hole, so that the machine has always operated in enough water to cover the cutters. This has so far eliminated the need for air to the cutter bearings. Air courses can be provided to clean and cool the bearings for dry drilling. The double swivel on the machine and separate pipes to each cutter permit compressed air from an outside source to be pumped to the bearings when a dry hole is being drilled. Dry drilling has been done using another circulation method by the U. S. Army Corps of Engineers. This system will be discussed briefly later.

Progress Data for Shaft No. 6 at Bunker Mine No. 2, Trotter Coal Co., Core, W. Va.

Diameter	75
Depth of shaft, ft	464.3
Depth drilled, ft	452.5
Total elapsed days (single shift) including holidays	79
Total drilling days	55
Feet per hour, including down time	0.93
Feet per hour, drilling time only	3.14
Feet per 8.8-hr shift	8.23
Feet per set of cutters	51.9
Feet drilled per trip	3.62
Trips per shift	2.27

Cutting Pick-Up: The vacuum system picks up cuttings and water, both of which are deposited in the cuttings chamber, which has a rubber flap valve on the outside of the barrel. The operator on the machine intermittently stops the vacuum motor,

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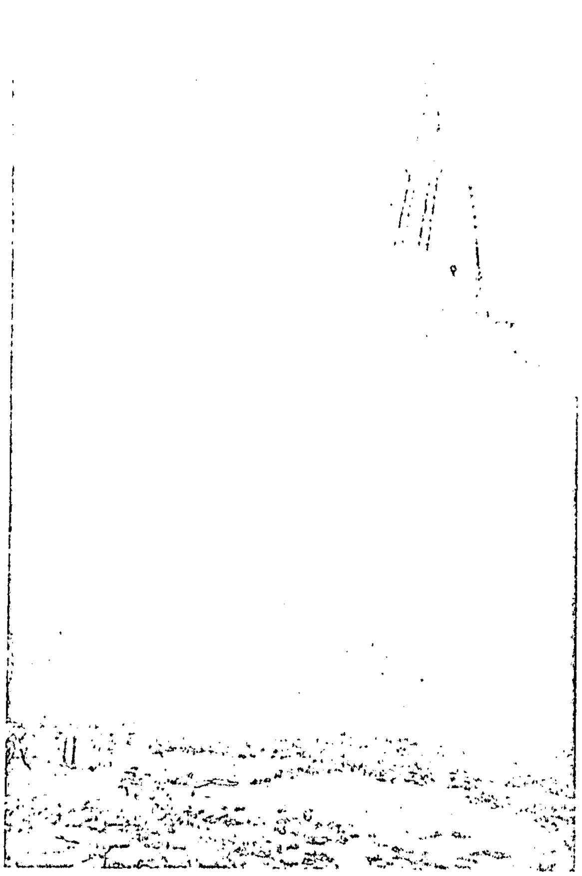
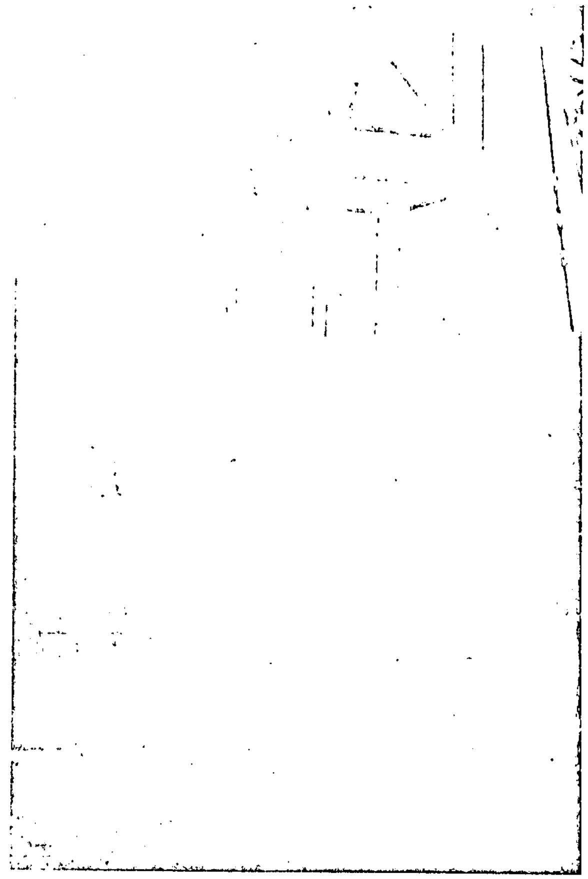


Special truck-mounted crane for handling core and equipment. All electric power is connected to the crane.



Core catcher made of two large rings separated by several longitudinal steel plates slightly longer than the 5-ft core.

which allows the flap valve to open and the water to flow from the chamber back into the hole.

Crew: A crew of four men is needed, two on the machine while it is in operation and two on the surface. Except during the core pulling, only one man at each place is busy, and during the drilling these two are only operating controls and recording data. To take care of any emergency, during drilling, two men stay on surface and two in the hole. The men do not ride the machine into the hole. A separate line with special bucket is provided for this purpose.

Operation: In drilling, the anchor and thrust jacks are set, the vacuum motor is turned on, and the core barrel is rotated. Telephone communication is maintained between the hoist men and the machine operator, and drilling times, hydraulic pressures, and other operating conditions are recorded at 2-in. intervals. This telephone report not only provides an excellent log of operations but also gives constant contact between surface and machine for safety.

Core Pulling: After about 5 ft of core has been drilled, the drilling machine is withdrawn and the core catcher inserted. The catcher is made of two large rings separated by several longitudinal steel plates, slightly longer than the core. There are cams on the inside of the lower ring with steel rollers held in a track or a cage. As the catcher is pulled, these rollers are forced into the core by the cams. While other crew members are pulling the core, one of the crew shovels and rakes the cuttings out of the upper drilling machine chamber.

A slight explosive charge in a small jackhammer hole drilled to the bottom at the center of the core has broken off all cores satisfactorily. This is accomplished with less than half a stick of dynamite. Many cores are broken without any blasting. In drilling a 400-ft shaft of this type in West Virginia, it can be expected that 10 pct of the cores will break up in the hole and require hand loading.

In dry holes the Army machine, previously mentioned and described later, had some difficulty in trying to break the core with a dynamite shot in the kerf. Two sticks of dynamite placed in the kerf against the lower part of the core and covered with several gallons of mud failed to break the core. One-fourth stick in a small hole drilled in the center broke them nicely.

Major Machine Revisions: Although the stiff leg derrick worked satisfactorily to handle this equipment, a special truck-mounted crane with more mobility was designed and built for the job. All the electric power is connected to the crane. From its control panels each piece of electrical equipment, both in the hole and on the surface, gets its power. The crane operator thus can start or stop the fan, the compressor, the power cable hoist, and the drilling rig at any time.

It was found after a few shafts that about 7 rpm would be satisfactory for all formations expected to be drilled. The multispeed transmission was eliminated to provide a stronger gear train. It was also found that 25 hp was inadequate for the rotary drive, and in its place two 25-hp permissible explosion-proof motors have been installed. Each of these has its own vertical shaft with pinion engaging the ring gear on top of the core barrel.

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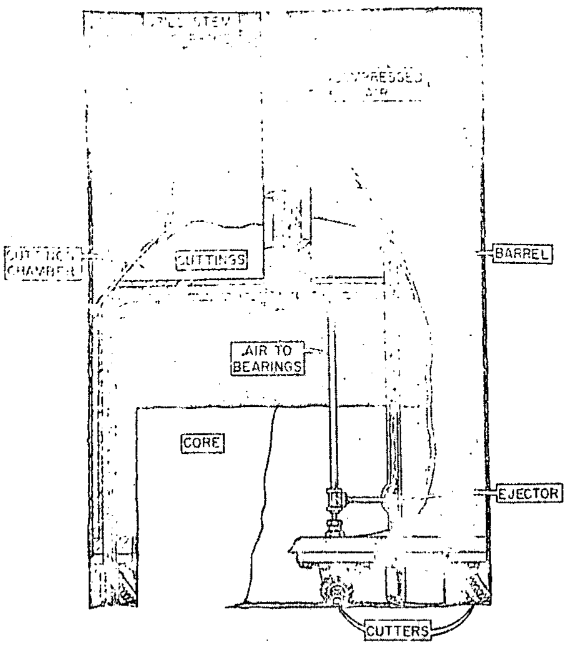
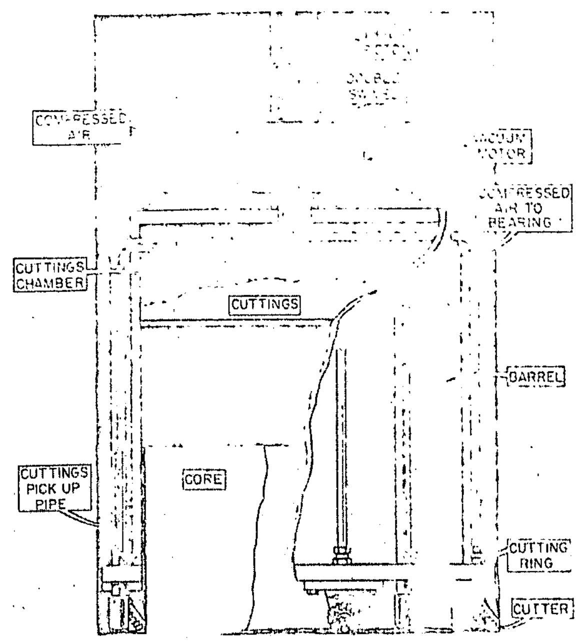


Vacuum circulation system.



Ejector circulation system.

Formations: Formations so far encountered in shaft No. 6 have all been sedimentary shales, limestones, and sandstones. They are soft, medium hard, and hard. No extremely hard formations such as granite or trap rock have as yet been drilled. Cutter life on shaft No. 6 averaged about 51.9 ft per set of six cutters. This is about average for all shafts. Cutter costs have been just under $8.00 per ft. Total costs of shafts of this diameter appears to be appreciably less than for other methods under comparable conditions. It appears from the data that on a three-shift basis, a 400-ft shaft could be completed at this location in 30 days.

Penetration rate has averaged about 3 ft per hr. Progress has been at the rate of about 8 ft per shift. Steps to reduce down time and increase the advance per shift are being considered on a machine to drill 8-ft diam shafts now being designed.

Other Related Tests and Developments

Army Tests: At their Research and Development Laboratories, Fort Belvoir, Va., U. S. Army engineers drilled 5-ft diam holes to 30-ft depths in hard limestone with a surface-operated rig. They obtained a vacuum by an aspirator or ejector effect with compressed air. This system worked very well, but the tests had to be stopped prior to the elimination of several mechanical weaknesses in the first set-up, as the machine was needed elsewhere on other types of work.

Casing: After the first Zeni shaft was drilled it was cased from the bottom up with 6-ft diam casing. Sections of casing 30 ft long were welded circumferentially in the shaft to the previously installed section. Special jigs and handling devices were needed for this work. Reamers and collapsible cutter mountings have been considered to allow casing to be done simultaneously with drilling in unstable ground in the future.

Man Cage: The Connelsville Mfg. Co. has designed a two-deck round elevator cage weighing 6500 lb to be used in these shafts. Ten men can be comfortably accommodated on each deck. This is a fully automatic passenger-operated counterbalanced system incorporating an overhead friction hoist and including many safety features. One of these is being used successfully in the first shaft drilled, regularly transporting 20 men each trip. About 1 min of travel time is required for 467 ft.

Positive Circulation to Clean Kerf: Subsequent laboratory tests have indicated that positive or direct circulation of air or water without using excessive volumes might be practical where formations or other conditions make it appear unwise to put a machine in the hole. This circulation method for large shafts, however, offers other problems not yet solved.

Conclusions

The rotary drilling system offers opportunities to drill shafts to 8-ft diameters and perhaps larger in any area where water can be economically controlled. Cutters have been made or designed for holes as small as 18 in. and for a wide variety of formations. Chief limitations on size are portability of equipment and the ability to break and handle cores.

The compact nature of the equipment makes it adaptable for drilling between levels underground. This system offers speed and economy in small and medium-sized shaft sinking. It also provides a finished hole with a minimum disturbance to the shaft wall and optimum conditions for ventilation if the shaft is to be so used. It appears to be one of the safest methods of shaft sinking so far devised.

Acknowledgments

The authors are indebted to the Zeni Corp. and the Hughes Tool Co. for providing the time and material for this paper. They wish particularly to thank E. A. Morlan, of Hughes Tool Research Dept., who was responsible for the laboratory work preceding this development and the design of the cutters.

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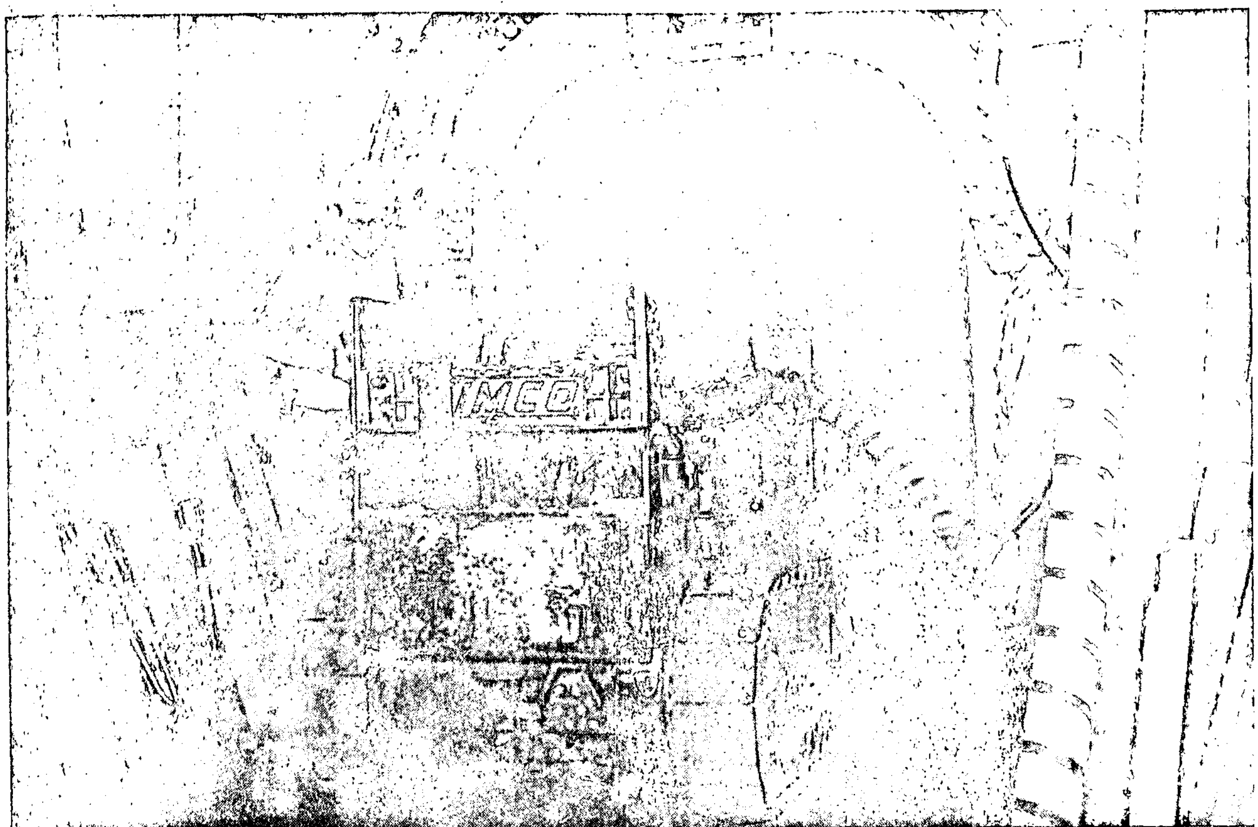


At A Sand Tunneling Project

AN EIMCO 630 DISPLAYS SPEED, POWER, VERSATILITY

Contracting firms at a large West Coast storm drain project employ a unique sand tunneling method that utilizes the loading speed and versatility of an Eimco 630 Crawler-Excavator.

The Eimco mucks at the base of a shield forced into the tunnel face by hydraulic rams bearing against the last set. The shield's broad apron sustains the ceiling and sides of the new cut until supports are installed.

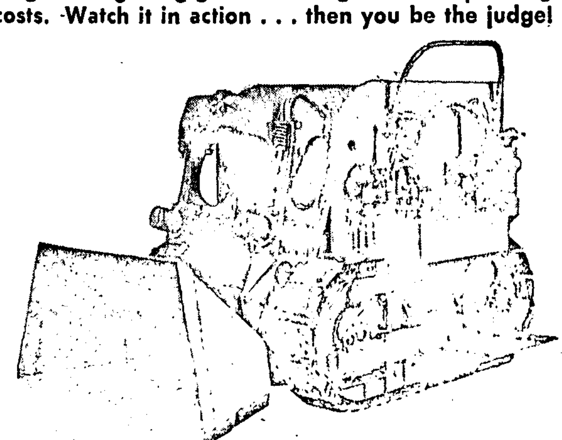
Here are some of the operating advantages being displayed by the Eimco 630:

1) **Loading Power . . .** Though procedure does not require blasting, material at the face is tightly packed. The Eimco's 6,000 pound digging power and independent track maneuverability (it crowds from any angle without making a new approach) are used advantageously to force the half-yard bucket into the face.

2) **Discharge Speed and Versatility . . .** The 630 reverses about 35 feet to discharge into a large hopper on side-mounted rails. To load in the cramped (10' rounded horseshoe) sections, the Eimco relies on overhead rocker arm discharge. While the machine moves from the face to the hopper, the operator gets the loaded bucket into dumping position . . . thus lost motion between excavating and discharge is held to a minimum. The Eimco traverses the 70 foot cycle and still dumps two cubic yards into the hopper every minute . . . enough to load a six (4 cu. yd.) car train every 14 minutes. Daily progress averages 35 feet.

3) **Dependable Service . . .** The Eimco is giving dependable on-the-job service while working in this abrasive sand . . . a real test of the machine's rugged and protective construction features.

The Eimco 630 is constantly meeting new challenges and getting greater tonnages at low operating costs. Watch it in action . . . then you be the judge!



THE EIMCO CORPORATION

Salt Lake City, Utah—U.S.A. Export Offices: Eimco

New York, N. Y. Chicago, Ill. San Francisco, Calif. Birmingham, Ala.
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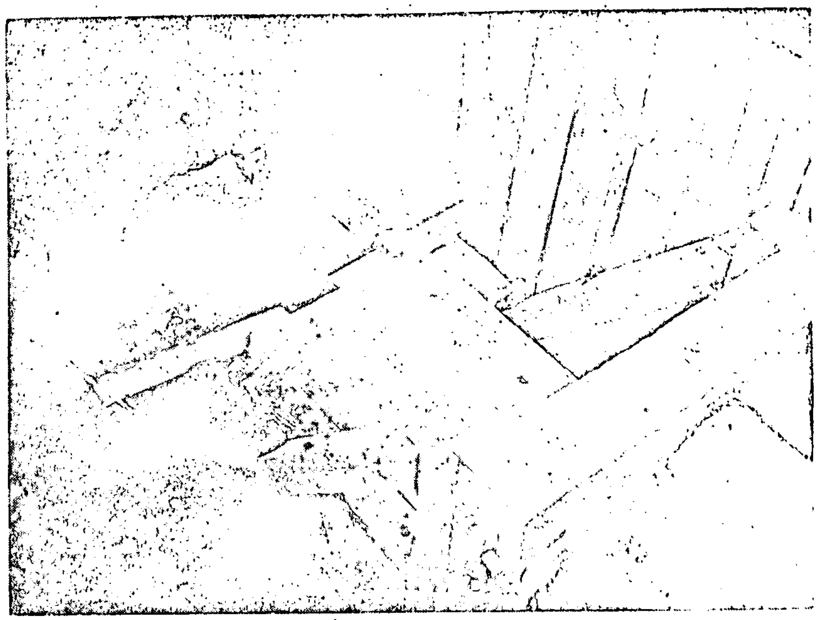
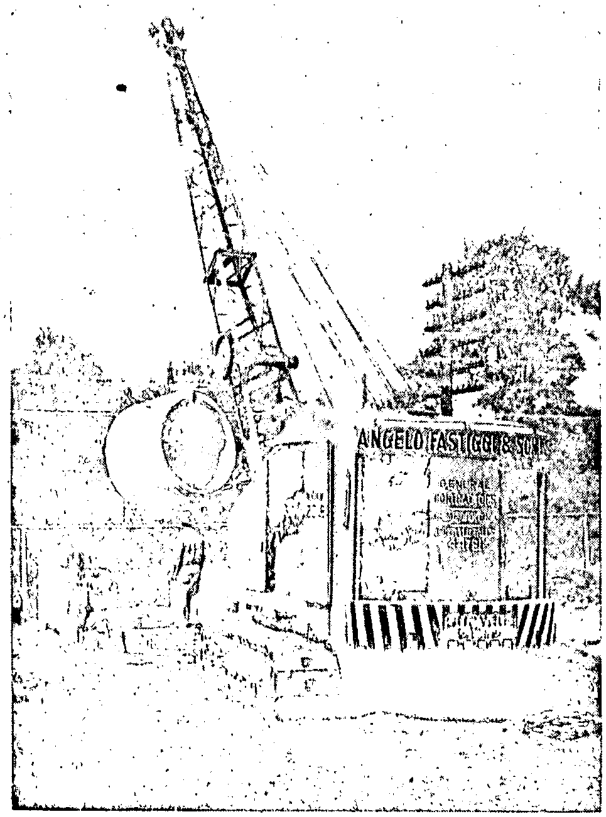
No. 22

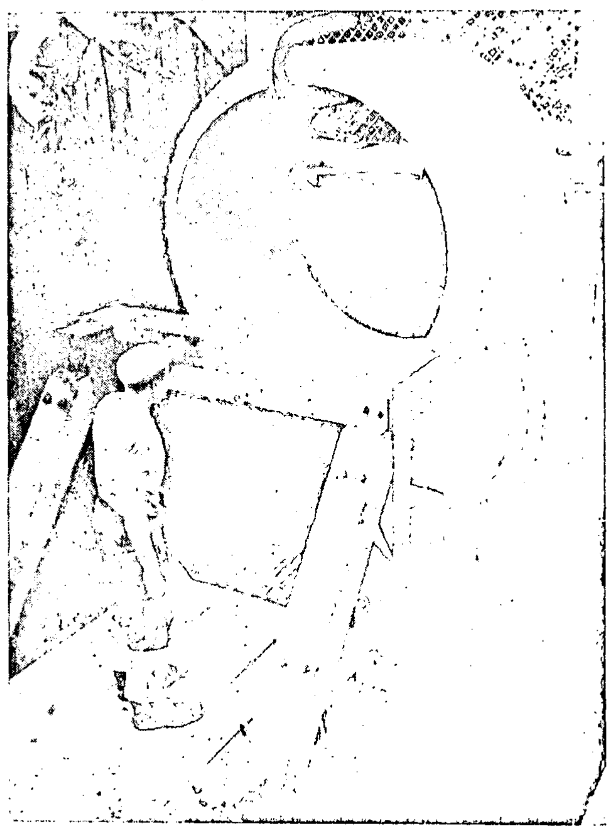
•The job was to drive 108 ft of 60-in. reinforced concrete pipe through the Central Railroad's 4-track embankment at Fanwood, N. J., for the township of Scotch Plains. Some 19 ft below rails and on a slight upward slope, the pipe was pushed 82 ft of the way by two 100-ton Joyce air-powered screw jacks. The rest was done in open cut. How contractor Angelo Fastiggi & Son Inc., of Cedar Grove, N. J., handled the jacking on its $15,700 sewer job is shown in the accompanying illustrations.



Air Jacks Push Pipe Through Embankment



PIPE IS HANDLED by hairpin hook slung from Bucyrus-Erie 22-B crane after delivery from near-by Lock Joint Pipe Co. plant. Each 4-ft section of this 60-in. ID concrete pipe with 6-in. reinforced wall weighs 3,600 lb. Railroad is at the rear.



SECTION IS LOWERED into 12x20x10-ft deep jacking pit that is sheeted and floored with 3-in. plank. Some 20 tons of broken stone below floor gives good drainage. Track on which pipe rests and jack frame rides is timber armored with steel plate.

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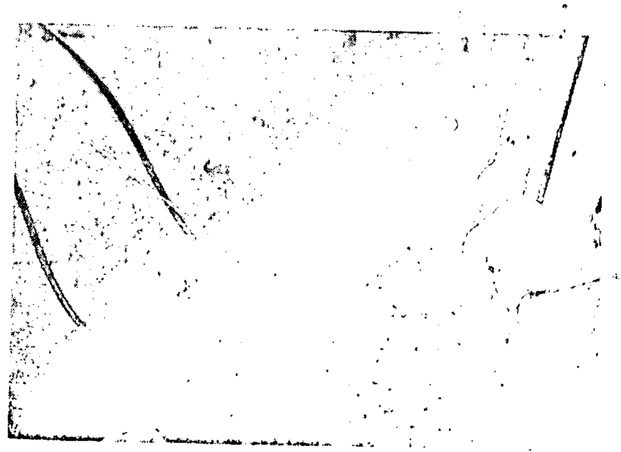
PIPE IS LUBRICATED with asphaltic paint before push to lessen friction. Jacking frame is of bolted, well-seasoned oak 12x12s. Frame's face bears against pipe's lip and shoulder.

JACKS ARE EXTENDED or retracted by air motors operated by 210-ft Chicago Pneumatic compressor. Normally used for lifting diesel locomotives, 100-ton Joyce jacks have 30-in. stroke.

FACE IS MUCKED OUT by hand as Ingersoll-Rand spade run by 105-ft LeRoi compressor loosens sandy, bouldery clay. Cutting edge on pipe end is 10-in. wide band of 1/2-in. steel plate.

SPOIL IS DUMPED into jacking pit from which it will be clammed out. Job works three shifts daily, advances average 7 ft in each. Wincharger generator supplies night-work light.

BLOCKING IS ADDED as necessary between jacks and frame, as pipe is pushed into embankment. Blocking timbers are generally 12x12-in. aged oak. Abutment at rear, which takes reaction of two jacks, is 10-yd, 10x12-ft concrete block 40 in. thick.



FRAME IS RETRACTED by wire rope from crane through snatch block anchored to abutment, so next pipe length can be inserted into line. Resting on top of self-retracted jacks is 1/2-in. steel plate that will be placed to prevent rams crushing frame.

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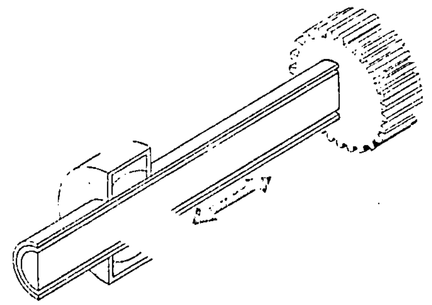
No. 23

Borer Uses 'Cradled' Torque T



Cradling the torque tube of this boring machine in a single spherical bearing gives limited angular positioning in any plane of its centerline. The torque tube supports a central boring head shaft.

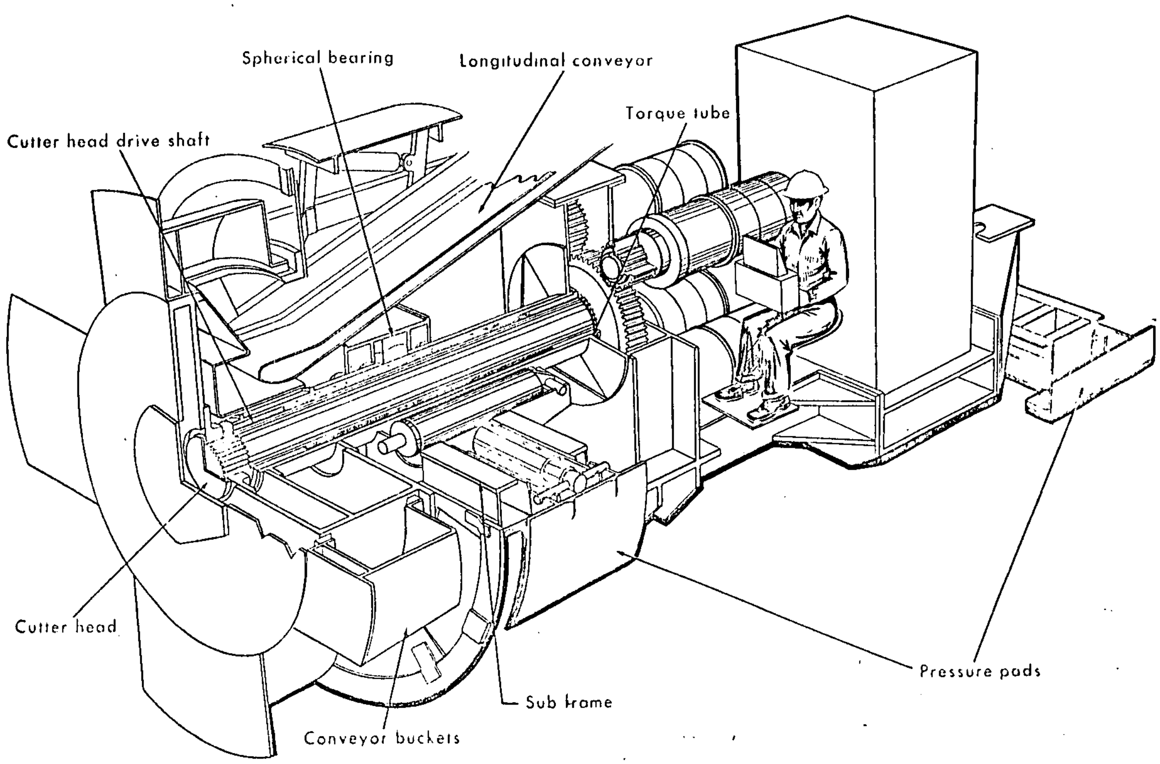
The outer race of the spherical bearing is supported on a sub frame, longitudinally adjustable on a pressure pad assembly. Relative motion between pressure pad assembly and sub frame forces cutter head into solid material to be removed. Angular motion between torque tube and subframe (movement in the spherical bearing) positions and changes direction of tunneling action.

Machine weight is carried on skid plates under sub frame and at rear of machine frame. Rear skids are mounted on four double acting hydraulic cylinders independently actuated to change angular attitude of cutter head. Each cylinder is fitted with a thrust tube to withstand side loading so that skid plates can withstand bi-directional loading.

Forward propulsion of machine is accomplished by releasing pressure pad cylinders and retracting feed cylinders. With feed cylinders fully retracted pads are forced into tunnel sidewalls and feed cylinders used to move machine forward on skid plates. This method of adjustment permits changes in direction without distortion of machine carriage.

To reduce size of main drive gear, thus allowing room for an overhead conveyor and other components to be placed around it, a four pinion drive is used. Electric drive motors, symmetrically positioned around main drive gear, give a more uniform loading to sleeve bearing supporting main drive shaft than would be obtained with a single gear drive.

The central torque tube, supported by the spherical bearing, serves as a structural backbone for entire boring machine. At forward end, torque tube is fitted with a bolted flange mounting a series of tapered thrust rollers. These rollers contact a raceway on back of boring head and transfer loading directly to cutting head. This removes all end thrust from main drive shaft. Simple sleeve bearings support main drive shaft in torque tube. Rear of torque tube is similarly flanged to mount four electric drive units and also serves as a closed gear case.



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'Cradled' Torque Tube to Allow Steering Adjustment

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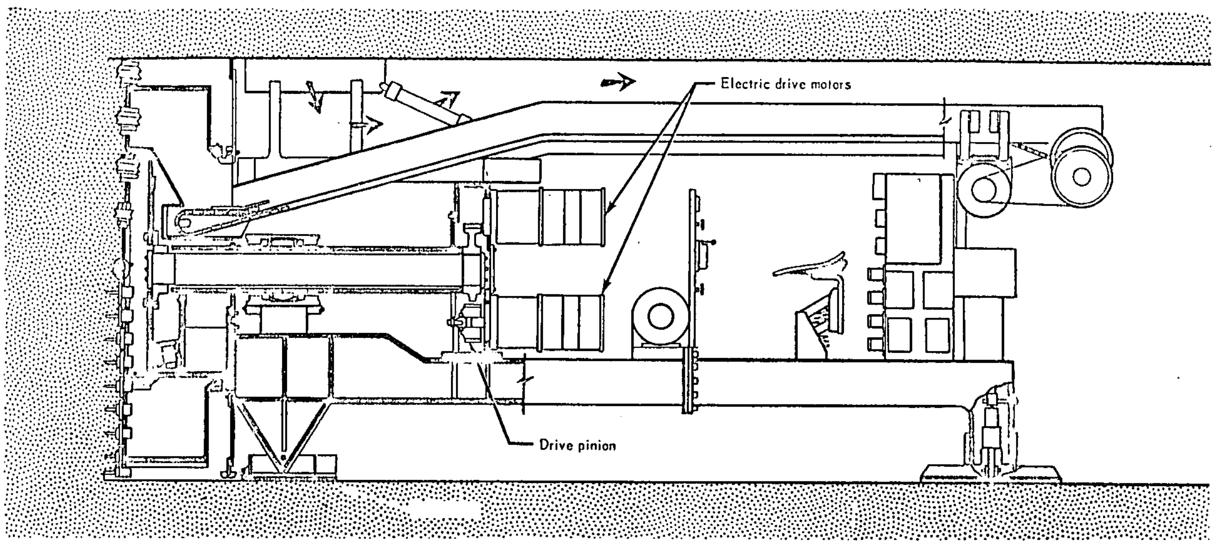
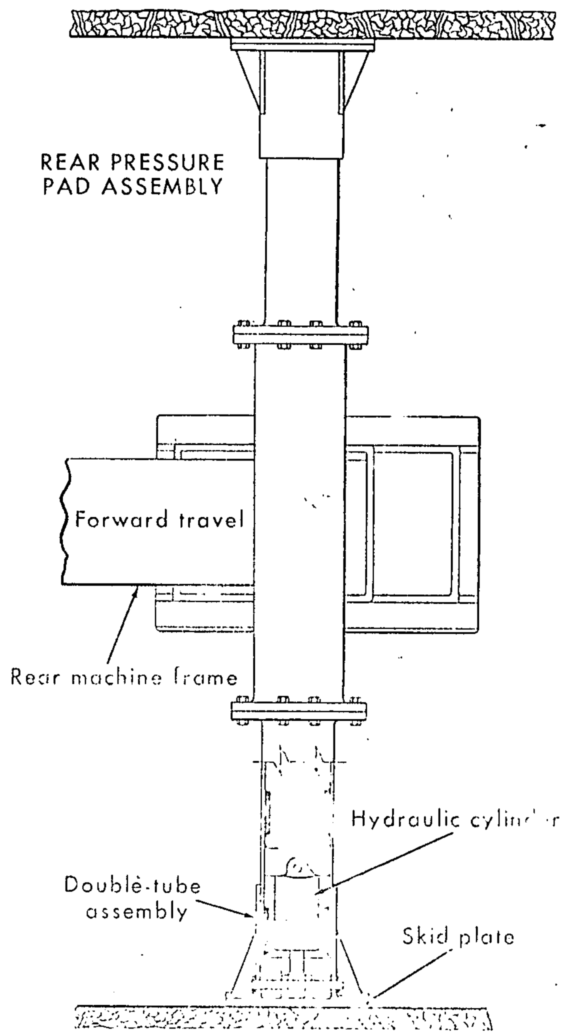


FOUR PINIONS on cutter drive equalize loading on shaft bearings and reduce size of gear teeth required to transmit a given torque to the cutter shaft. Four electric drive motors and pinions are interchangeable, which reduces inventory required for replacement parts. Forward crowding action moves entire machine on skid plates. At the end of feed cylinder stroke, curved pressure plates are retracted and feed cylinders used to re-position pressure pads longitudinally for a new reference point. Skid plate is designed with series of narrow strips running in direction of travel. On rigid material, skid rides only on strips, thus reducing frictional resistance to forward motion. When material will not support weight on runners, entire plate area is used. Movement differential between support on runners and support on entire plate is small and therefore does not affect positioning of cutter head materially. Detail shows rear positioning cylinder. Note that double tube assembly carries side loading on cylinder.



SINGLE SPHERICAL BEARING 16 inches in dia between boring head torque tube and supporting sub frame permits angular adjustment to change direction of boring. Four individually positioned double acting hydraulic cylinders located at rear of frame (two vertical and two horizontal) are opposed to provide universal adjustment. Reaction forces are transferred to tunnel wall by curved pressure pads forced into sidewall by hydraulic cylinders. Cutting head is forced into rock face by a pair of hydraulic cylinders on either side of torque tube. Safety interlock prevents actuation of these cylinders until pressure is applied to pressure pads. Clockwise rotation of cutter head loosens material and moves it into the conveyor buckets which discharge onto a longitudinal conveyor. The machine is a design development of James S. Robbins and Assoc., S[illegible]

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No. 24

BORING BEATS TRENCHING for UG Construction in Congested Areas

By
J. BOGDANOWSKI
Superintendent, Methods Division, Survey and Methods Bureau, Outside Plant Construction Department, Consolidated Edison Company of New York, Inc.

New machines and techniques accomplish earth boring jobs at reasonable and consistent cost where open trenching and tunneling would be economically impossible; boring is done accurately, on year-round schedule, with minimum disruption of traffic and inconvenience to public.

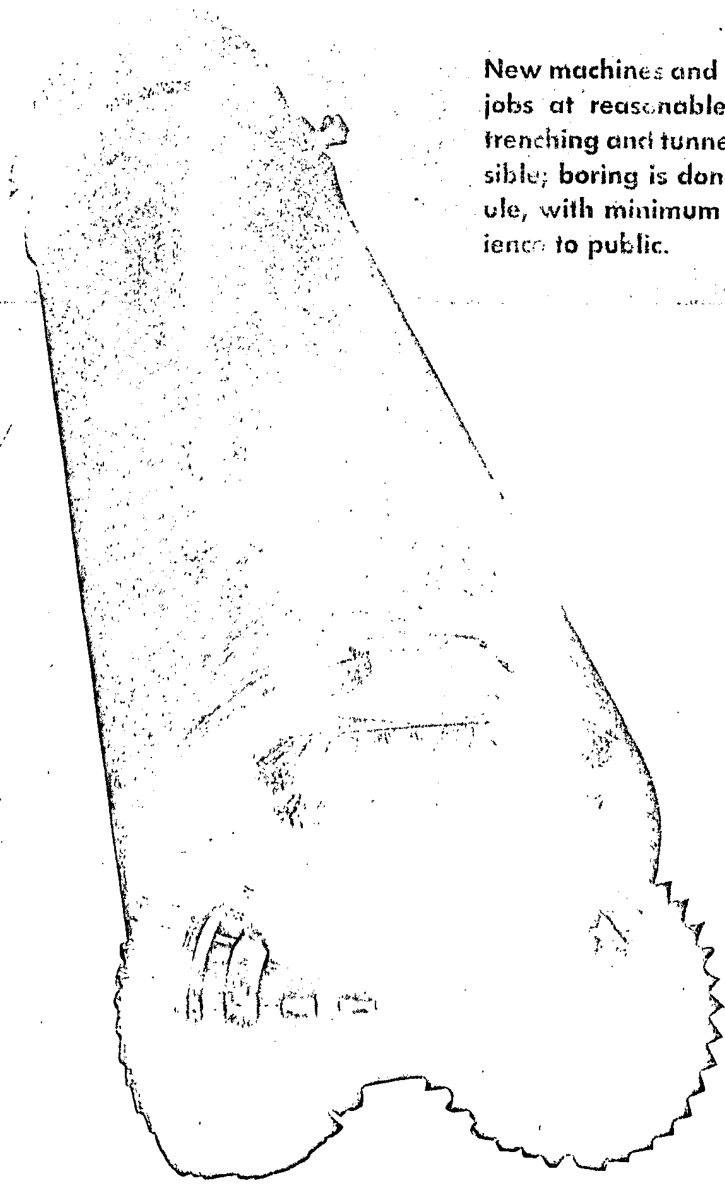

Fig. 1—A tri-cone rock bit, with tungsten carbide teeth, capable of cutting its way through rock, is welded to the lead end of the pipe; it is the type used in oil well drilling operations.

FACED WITH the daily task of installing underground electric conduit, gas and steam mains in the New York City area, Con Edison has found that it is not always economical or practical to effect this construction by using open trench methods. Traffic density on city streets limits excavations to a minimum and, very often, construction must be accomplished during off hours or week ends. Moreover, open-trench construction is completely out of the question in many places, such as express highways, railroad rights-of-way, etc. These conditions, coupled with ever-expanding demands for electric, gas, and steam service, resulted in costly installations and led to the development, over several years, of methods and machines for horizontal earth boring. The company is now at a point in this development where some 12,000 ft of underground structures are installed annually. These are spread over approximately 150 different jobs with bores ranging from one-in. to 30-in. in diameter, and from 30 to 340-ft. in length.

Three years ago, Con Edison entered into an agreement with Boring, Inc., a contractor, to handle all boring jobs. Under this agreement, both the company and the contractor furnished machine equipment and technical know-

Editor's Note—This is the essential text of a paper presented by the author at the May, 1957 meeting of the Transmission and Distribution Committee, Edison Electric Institute, Kansas City, Missouri.

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how. The contractor furnishes field personnel and experience to fit company requirements. To date this arrangement is working out to the satisfaction and benefit of both parties. In addition, the arrangement permits the company to purchase boring jobs on a unit cost-per-foot basis, just as open-trench jobs are purchased.

Method Used

There are a number of ways to propel a piece of pipe through the earth. Some of these are known as plain jacking, augering and jacking, and jetting. Machines and accessories are commercially available from a number of manufacturers for these various methods, but none of them are designed for propulsion through earth containing rock formations or boulders.

Experience in the New York City area has shown that from 20 to 100 percent of boring jobs is rock cutting. Rock- or boulder-free jobs are the exception rather than the rule. This condition, coupled with the requirements of accuracy in hitting the target with minimum deviation and maintaining production schedules led to development of our particular method and type of equipment. We call the method "Boring and Jacking."

In this arrangement all pipes are rotated and propelled through the earth by a drill machine and a system of hydraulic jacks. A tri-cone rock bit, Fig. 1, with tungsten carbide teeth, capable of cutting its way through rock, is welded to the lead end of the pipe. It is the same type rock bit used in oil well drilling operations.

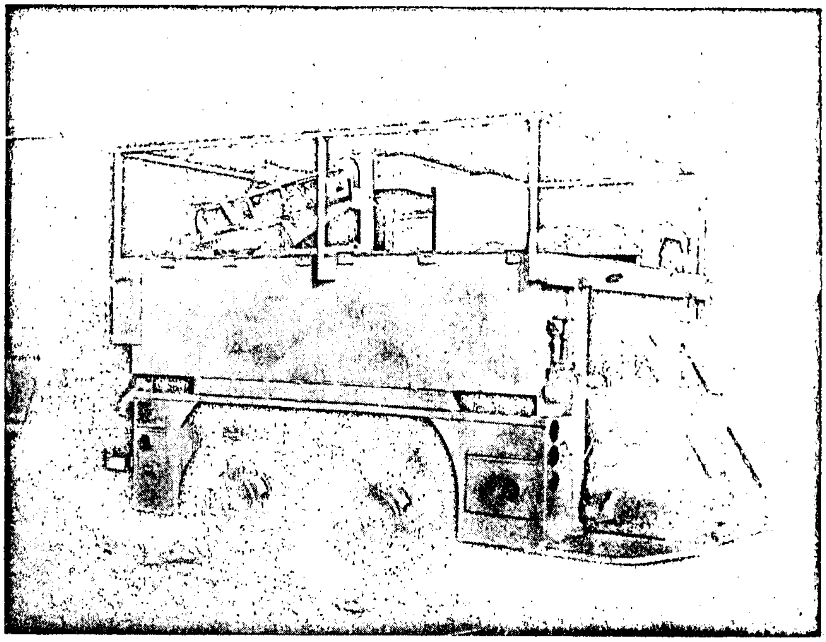

Fig. 3—This self-contained, compact boring machine drills pipes in the four to eight-in. diameter range for a distance of 150 feet. Like the smaller unit shown in Fig. 2, it requires no assembly in the field.

Boring Technique

A feed pipe, mounted concentrically in the drill pipe and connected to the drill bit box, conveys a liquid slurry to the bit. A commercially available material known as "Aquajel," a barium-sulphate compound, mixed with clay and water, forms the slurry which is pumped to the head end of the pipe and through the bit as it is propelled through the earth.

The slurry serves a three-fold purpose: it lubricates the bit and bore

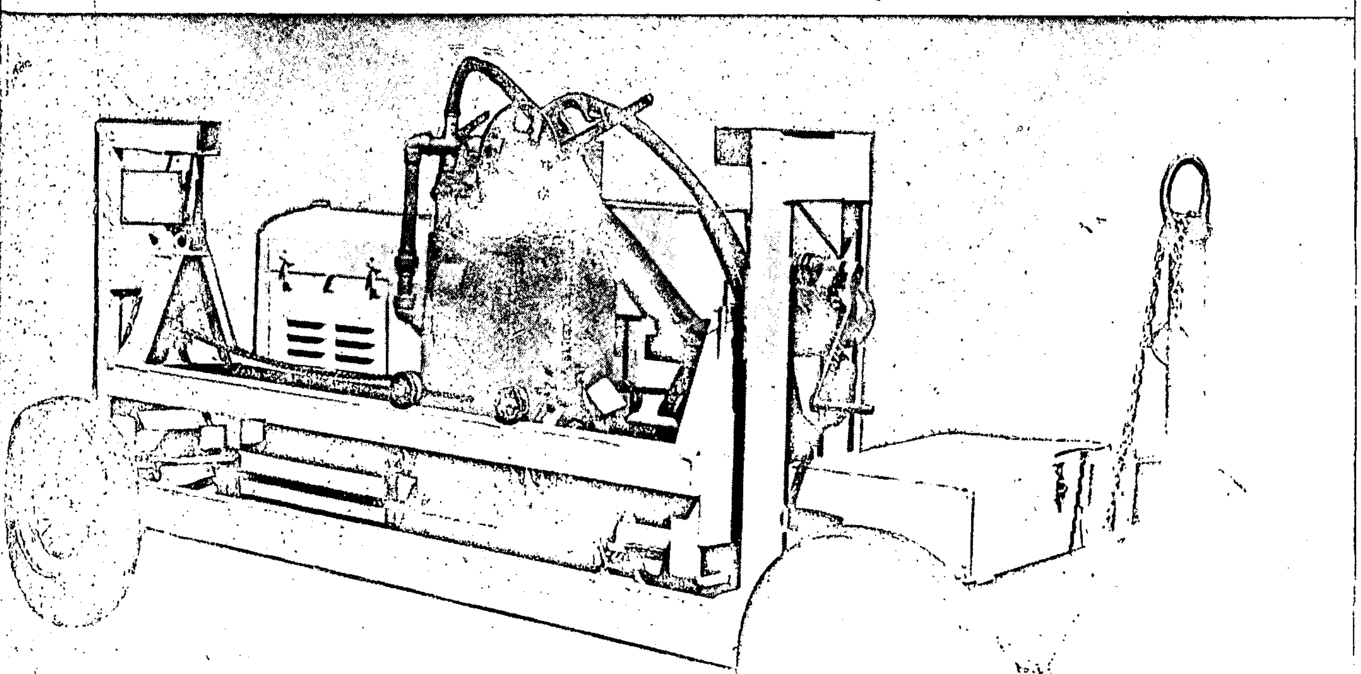

Fig. 2—The two-in. portable unit is primarily for mid-block and street intersection boring. It is a self-contained machine capable of making pipe bores 30 to 90 ft long in three to four hours.

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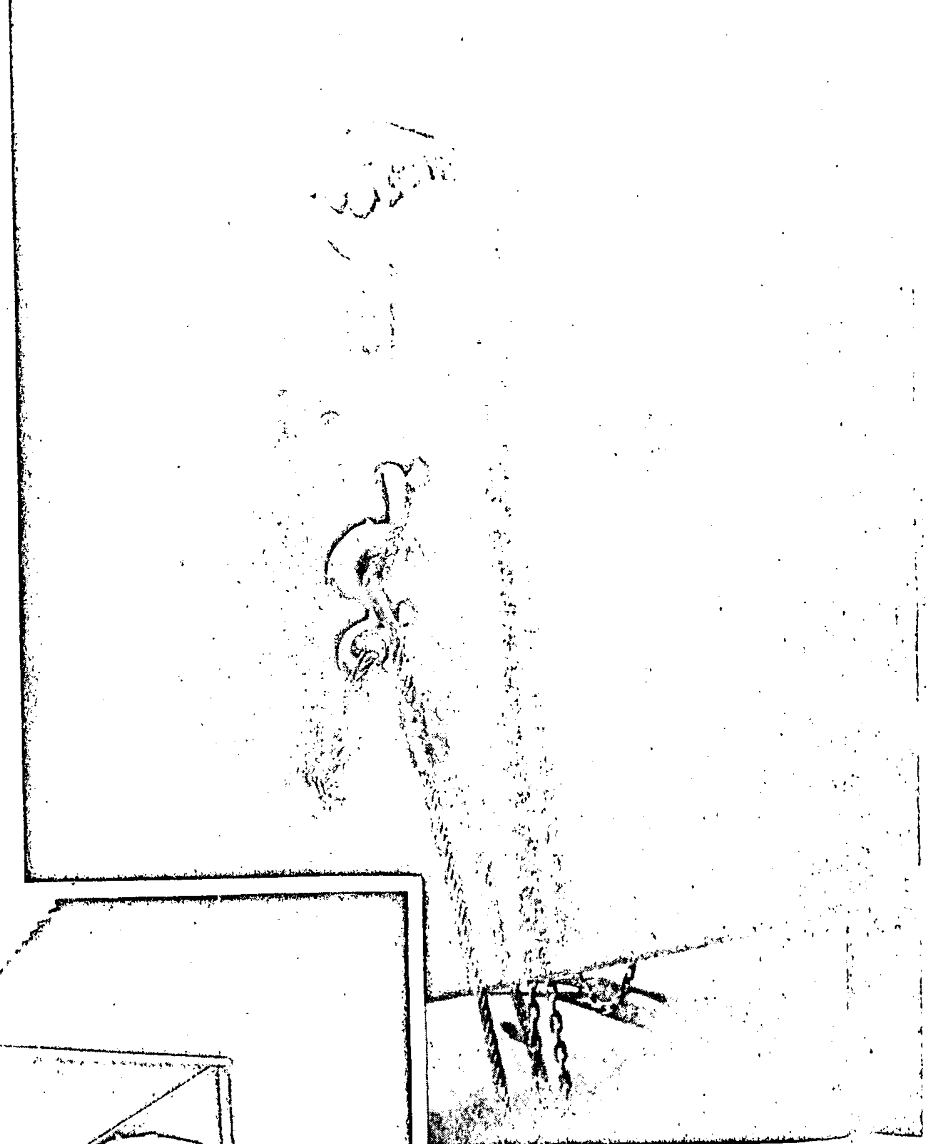
hole; it cools the bit; and it acts as a vehicle to carry the rock chips and soil back to the boring pit. At the boring pit the contaminated slurry is sucked up and pumped to a vibrating shaker screen which separates spoil from slurry. The latter is then recirculated.

Two-Inch Portable

To conduct these operations in the field, the company has designed and constructed a number of different types of machines. One of these, known as the "Two-Inch Portable," (Fig. 2) was designed primarily for mid-block and street intersection boring. It is used daily on new street-lamp service pipe installations.

An eight-foot by 20-in. trench is dug, usually on the sidewalk, alongside the lamp-post. The trailer-mounted machine is rolled over the excavation, the scaffold containing the boring unit is lowered into it, aligned and chocked. The machine is then ready to bore. Pipe bores from 30 to 90 feet are made with this arrangement in three to four hours. Three such units are now in use on the Con-Ed system.

This trailer-mounted machine consists of a 26-hp gasoline engine coupled to a 30 gpm, 1200 psi hydraulic pump which is connected to a 15-hp 1200 rpm hydraulic motor with a pair of flexible hydraulic high pressure hoses. The hydraulic motor is part of the gear reduction assembly mounted on the scaffold portion of the trailer. This unit furnishes rotating power to the drill pipe at a speed of 40 rpm and a maximum torque of 23,000 in.-lb. This machine does not use power jacking for forward propulsion; this is obtained manually through a roller chain assembly and a ratchet comealong. Experience in boring with pipe sizes of one- and two-in. diameters showed a tendency on the part of machine operators to force drilling operations with power jacking with the result that bores were deflected from the target.



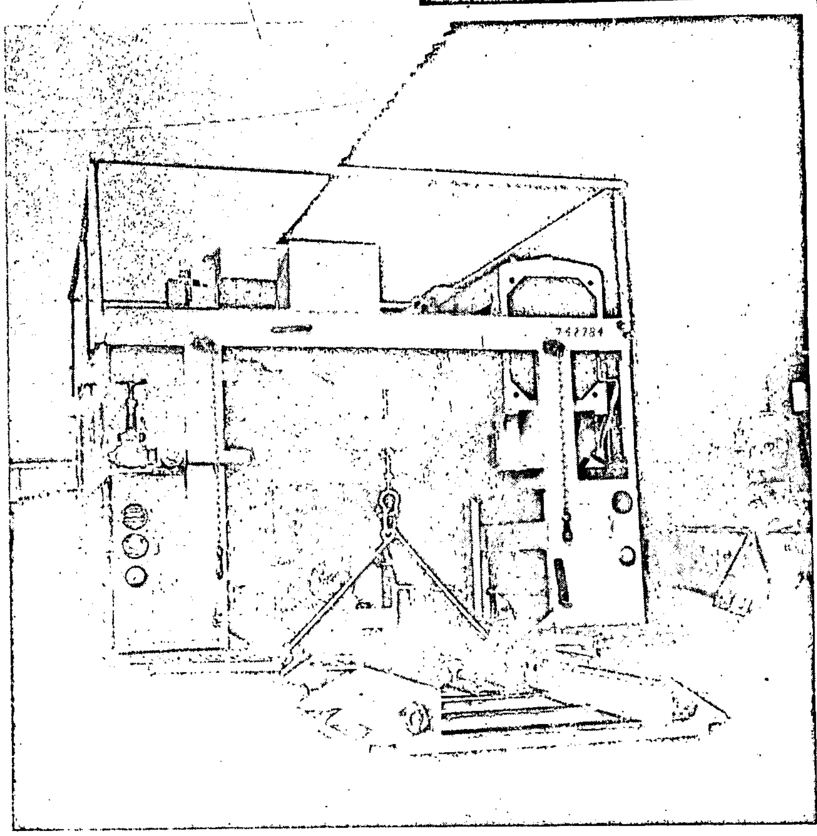


Fig. 4—Rear-view of machine illustrated in Fig. 3 shows track rail off the trailer hooks ready to be lowered by the unit's electric-driven elevator into an excavation for the boring operation.

Self-Contained Unit

Another valuable machine in the new

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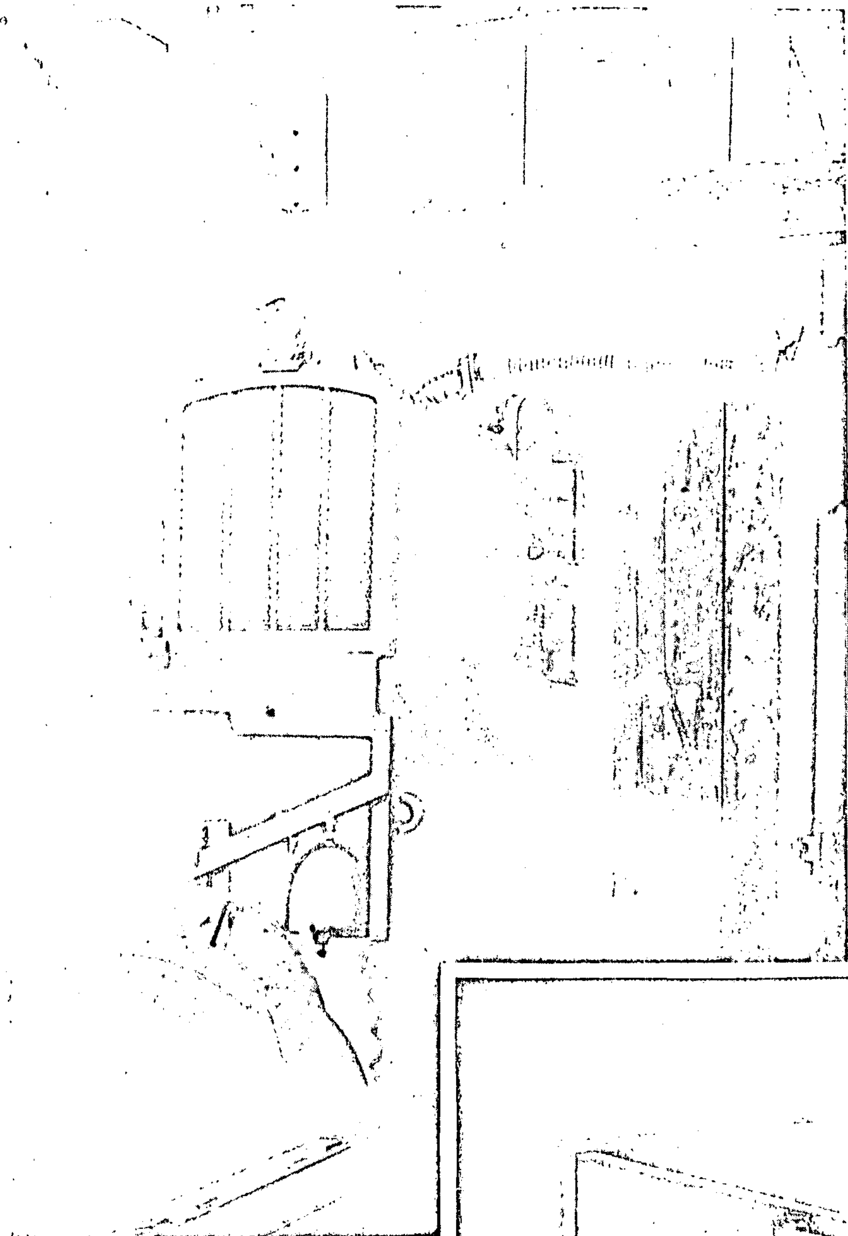

Fig. 6—This giant power-packed boring unit bores pipes from 16 to 30 in. in dia. for distances of 300 ft or more. The engine is a 200 hp GM diesel with integral torque converter, and hydramatic transmission system.

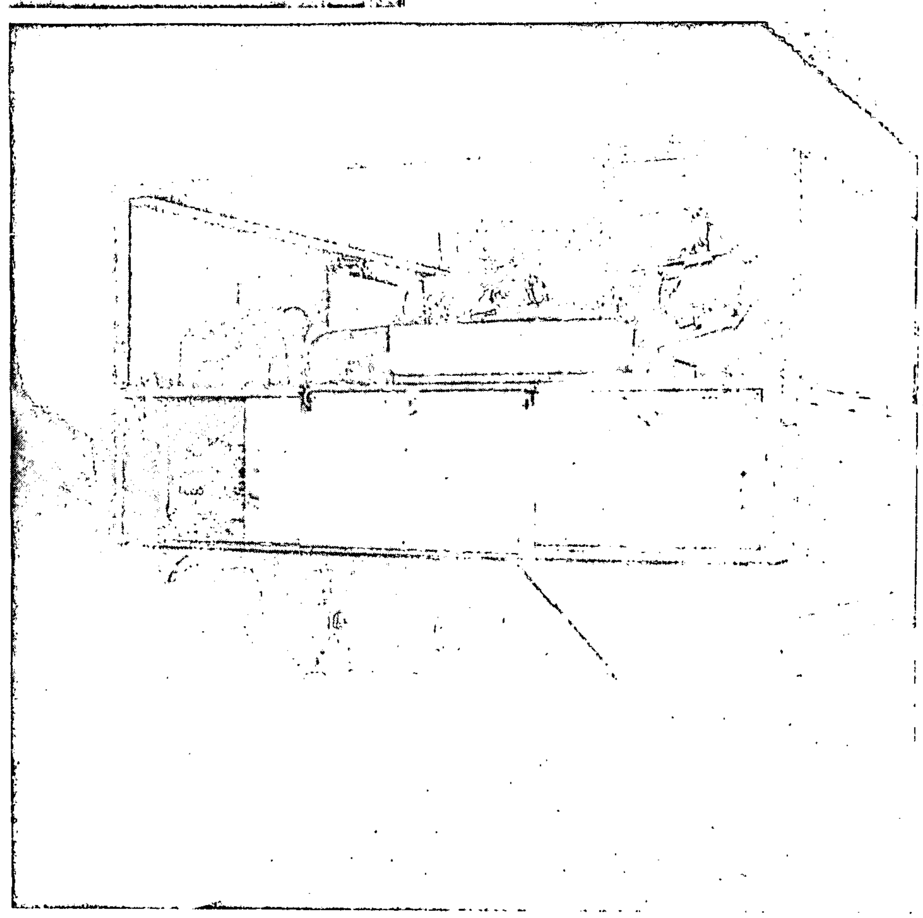

Fig. 5—Front view of machine illustrated in Fig. 3 shows vibrating shaker at top, control box at left, and suction pump at lower left mounted on tow bar apron.

series is shown in Figs. 3, 4, and 5. Built on the chassis of what was once a U. S. Army searchlight trailer, the unit is compact and self-contained, ready to roll to a job location. It is 14-ft long, seven-ft ten-in. wide, and eight-ft six-in. high. In use, the unit covers 70 percent of the excavated area over which it sits, leaving only a small portion that needs protection. It literally lifts itself by its own bootstraps and is capable of drilling pipes from four-in. to eight-in. in diameter for a distance of 150 ft. Like the "Two-Inch Portable" it requires no assembly in the field and has proven to be a real time and money saver in boring operations.

The rear view of this machine, Fig. 4, shows the track rail off the trailer hooks, being lowered by an electric-driven elevator. In the upper right may be seen the gasoline engine, rated 70 hp, used to drive an oil pump which is connected to a hydraulic motor that is part of the boring unit mounted on the rails. At the upper right rear interior part of the trailer is a two-gpm 7500 psi hydraulic pump which furnishes propulsion power to the two 20-ton cylinder jacks that engage the notched rail and push the boring unit forward. At the left, directly behind the valve, is a 500-gal. slurry tank that runs the full length of the trailer body.

The front view, Fig. 5, shows the vibrating shaker mounted on the top deck. The suction pump is at the lower left, mounted on the tow-bar apron. At the lower right side, in the cutaway portion of the tow-bar apron, a barrel is placed on the ground to collect the cuttings and spoil that is separated from the slurry and dropped through

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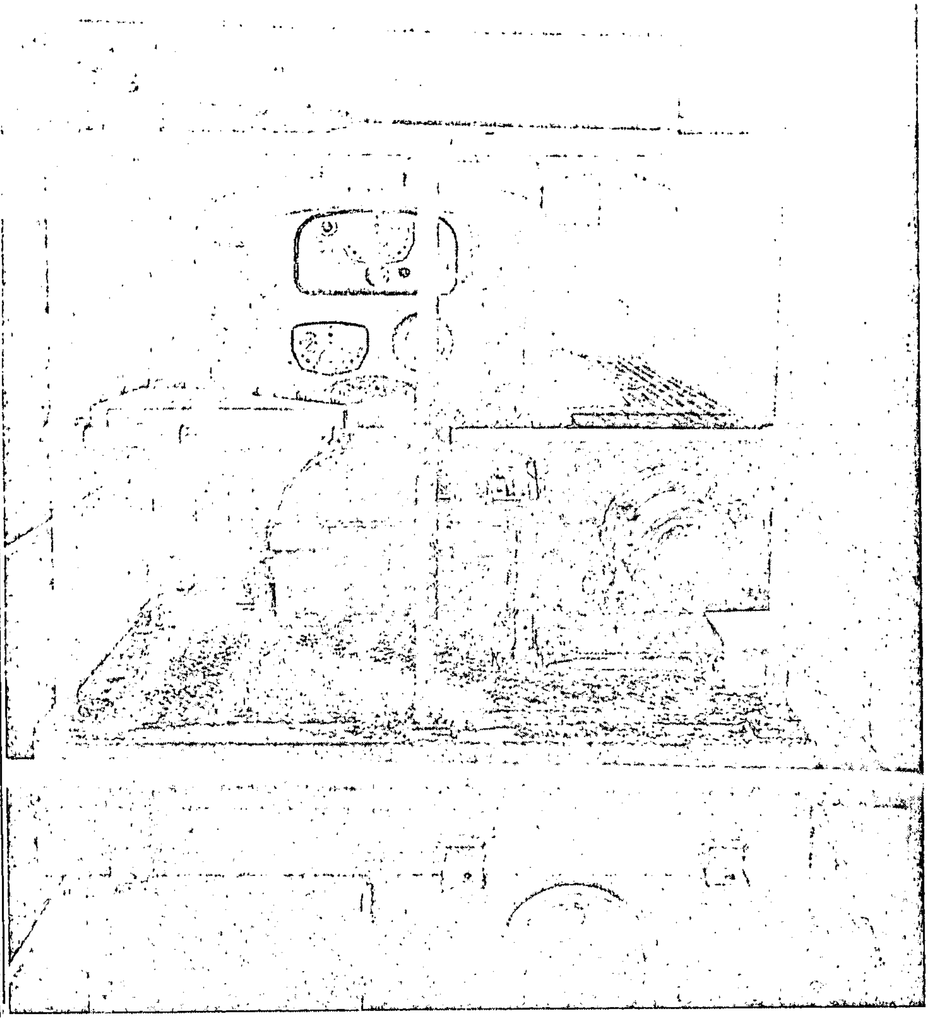
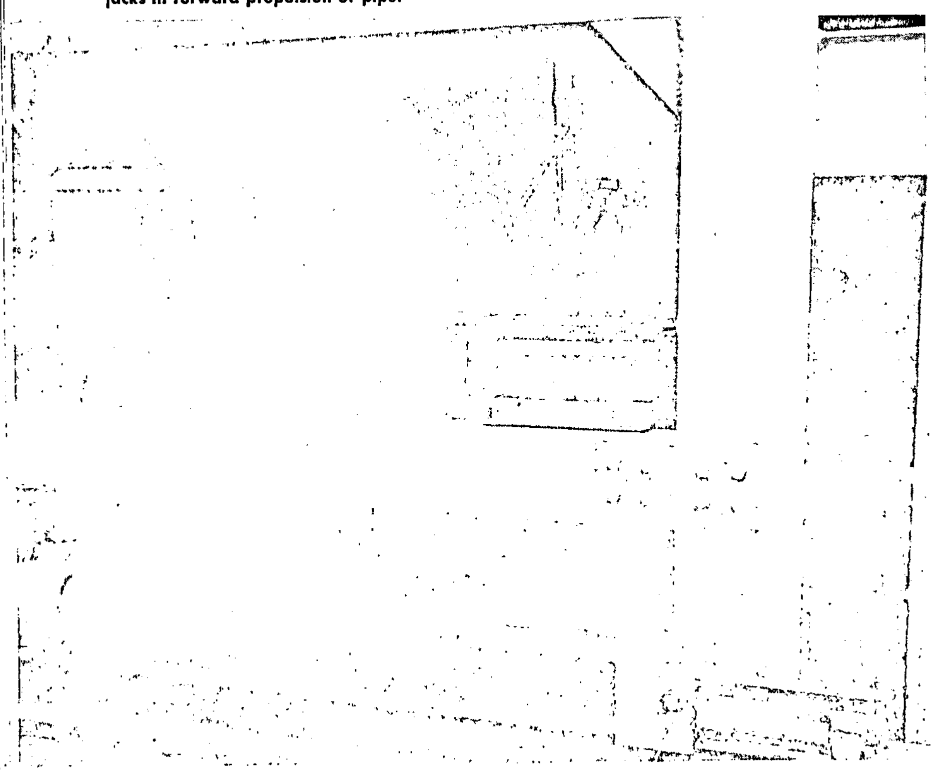


Fig. 7—Control deck of machine illustrated in Fig. 6 showing gear reduction box and control panels.

Fig. 8—Close-up view of middle deck of machine illustrated in Fig. 6 showing one of two 50-ton cylinder jacks partly extended on reaction rail; at top left is high-pressure oil pump that actuates jacks in forward propulsion of pipe.



the duct mounted on the front wall. Circuit breaker switches are visible in the partly-open cabinet at the left; these control and actuate electric motors, high-pressure oil pump, slurry pump, shaker screen, and elevator.

Since most of the work is performed on public streets and highways, the new equipment was designed for quick set-up, a minimum of field-assembly operations, and a minimum need for work-area protection. We believe that the less time a crew spends at a work location and the less space occupied in doing a job, the more we contribute to better public relations and over-all economy.

Fourteen-Ton Giant

Largest of the new series of machines is a power-packed giant weighing 14 tons capable of boring pipes from 16 to 30 in. in diameter for a distance of 250 ft or more. (See Fig. 6). The machine is shown in a coffer dam on the east shore of the Harlem River opposite Con-Ed's Sherman Creek generating station, in position and ready to bore the first of four 24-in. dia. sleeves, each of which will encase two pipe-type 132-kv feeders. Each sleeve in this bore was 110-ft long and ran under the mainline tracks of the New York Central R.R. leading to and from the Grand Central Station. The machine, as set up, handled 20 to 22 random length of pipe.

Fig. 7 is a right-rear view of this machine showing the control deck and the gear reduction box. The engine is a 200-hp General Motors diesel with an integral torque converter, connected to an Allison hydramatic transmission via a system of silent chains and counter-shafting. The transmission is connected to the input end of the gear reduction unit whose final drive is coupled to the main pipe boring shaft. The transmission has three forward speeds and one reverse. The combination of these components is such that speeds of rotation from four to 40 rpm can be obtained. Maximum torque of well over 1,000,000 in.-lb can be transmitted to the pipe at four rpm, a lot of torque for a mobile unit of this size.

This boring machine is 12-ft high, 11-ft long, and 48-in. wide over its carriage rails. The front drive plate is 38-in. in diameter and contains three drive bars, spaced 120 deg. apart, that can be varied radially to engage any size pipe from 16 in. to 36 in. in diameter. The track carriage rail consists

(Continued on page 169)

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Sanitized Copy Approved for Release 2011/06/28 : CIA-RDP78-03642A002400070001-7

BORING BEATS TRENCHING—

(Continued from page 140)

of two 18-ft sections. This unit can be disassembled for transportation. The smallest excavation in which this machine can be operated is 19-ft long, five-ft wide; depth is determined by depth at which the pipe is required.

A close-up view of the left side of the middle deck of this machine is shown in Fig. 8. One of the two 50-ton cylinder jacks may be seen in a partly-extended position on the reaction rail. The high-pressure oil pump that actuates the jacks in forward propulsion of the pipe may be seen in the upper-left corner. Total pressure of 100 tons can be impressed on the pipe with this arrangement. At the top center, the hydramatic transmission may be seen; below and to the right are two 12-volt starting batteries.

This machine, due to its size and weight, is not totally self-contained. A trailer containing slurry tanks, pumps, shakers, and pipe ties is a separate piece of equipment.

On its maiden run, this giant machine was instrumental is saving the company a considerable amount of money over the accepted standard methods of open trenching or tunneling. Slow-down of train traffic on the N.Y.C. main line was eliminated, and all four bore runs were completed on schedule. Approximately 39-ft of rock had to be bored through in each of the four bores.

Intermediate Size

In the band of pipe sizes from eight to 16 in. the company still employs several older machines which will soon be replaced by two 150-hp machines now under construction.

Cost Comparison

An evaluation of construction by the horizontal earth-boring method for the years 1955 and 1956 shows that:

(1) On normal city streets boring costs were from 80 to 100 percent higher than open trench costs.

(2) Under railroad right-of-ways boring costs were from 25 to 60 percent lower than open trench costs.

(3) Under parkways and congested city streets boring costs were 10 to 20 percent lower than open trench costs.

(4) Over-all cost of work completed during the two years was 11 percent below open trench costs. These percentages are based on approximately $750,000 worth of underground construction.

Summary

Summarizing the company's earth boring progress to date we find that:

(1) We can install various underground conduit structures at a reasonable and consistent cost.

(2) We can bore through rock formations at rates from 14 in. to four-ft per hour.

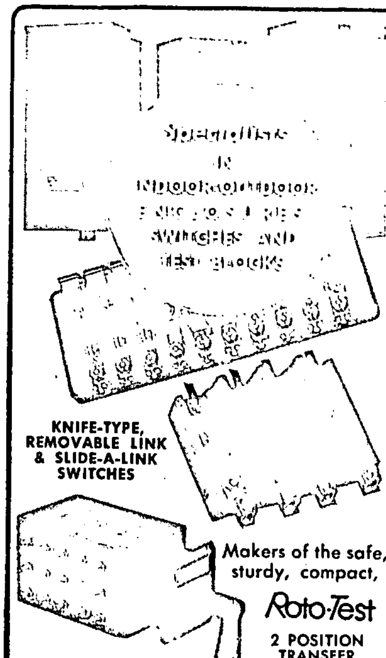
(3) We can bore through earth soils at rates from 30 to 40 ft per hour.

(4) We can install underground conduit structures below present congested levels, where open trenches and tunneling methods would be economically impossible.

(5) We can always hit our target with a minimum of deviation from line and grade.

(6) We can operate on a schedule basis all year round.

(7) We can install facilities with minimum disruption of traffic and inconvenience to the public.



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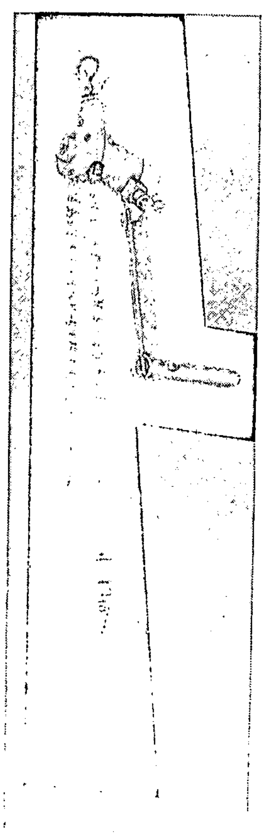

The 9½ pound Coffing Mighty Midget Puller Lifts 1000 POUNDS

Lightweight and compact Coffing Mighty Midget Pullers are handy lifting tools for all kinds of operations in plants and in the field. The 1000-lb. capacity models weigh but 9½ lbs., and will lift the full load with only 40 pounds of handle pull. The 500-lb. model weighs 6½ lbs., and 28 pounds of handle pull lifts the capacity load.

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For full information on these sturdy pullers, consult your distributor or write to us for Bulletin MP. **Coffing Hoist Division, Duff-Norton Company, 807 Walter Street, Danville, Illinois.**

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No. 25

THIS CHAPTER TO BE FILED UNDER: Natural Gas

A Continuing Educational and Reference Course in Gas Technology, Management, Equipment, Operations, and Utilization

Completing the Gas/Oil Well

AFTER a well has been drilled to the desired depth, casing must be set to provide a permanent hole for the production of gas and oil at the surface for use or sale. The techniques involved are referred to in the oil field as **completion operation.** The importance of this phase of activity in securing production is reflected in the relationship of its cost to that of drilling the well. The materials and services used in completing and equipping the well amount to roughly *twice* the cost of drilling the hole. In addition, great skill, training, and experience are mandatory of the personnel responsible for completion work to insure maximum economic benefits.

Setting Casing

Various factors influence the amount and size of casing that may be used in a well. In the previous chapters on *Methods of Drilling* it was pointed out that an *initial or surface string* of casing is necessary to provide an anchor for the blow-out preventers. The surface string is also needed to shut off the entry of water into the hole from surface sands and to prevent contamination of those same sands with mud, salt water, gas or oil from the drilling well. The length of this pipe in the hole may vary from 50 to 1500 ft.

Between the base of the surface casing and the total projected depth of the well, other conditions may be encountered that will require casing to protect the hole and permit continued drilling with safety. Pipe, used in this manner, is referred to as *intermediate casing.* It may be used to seal off strong water flows or to bolster weak hole walls. Sometimes soluble materials, such as salt, are encountered that will endanger continued drilling unless they are isolated with casing.

Finally, the pay section is reached and all points between it and the surface must be excluded to permit effective production. This is called the *production string.* Different considerations dictate the base point for setting of *landing* this casing.

When the production string of casing is run, the operator has the choice of setting casing through the pay or on top of the pay zone. If the casing is cemented at the top of the productive horizon, in what is known as *open hole completion,* this may be accomplished with special cementing tools after drilling through the zone. Or, the hole may be drilled to the top of the pay, casing run, and the productive section drilled out below the pipe after the cement has set.

The advantages of setting casing through the pay zone are that the operator has more control over the entry of gas, oil, and water into the well and the ability to be more selective as to the portions of the rock to be tapped for production.

After the cement has hardened around the casing, the oil or gas from desired portions of the strata is conducted into the casing by holes made through the casing and cement.

These *perforations* are created by shooting bullets from specially designed guns through the steel casing wall and cement jacket into the surrounding stratum. There are many designs and sizes of perforating guns but all are lowered into the hole with cables running over carefully calibrated reels that compute the position of the gun in the hole. In this manner, the gun is stationed precisely for firing.

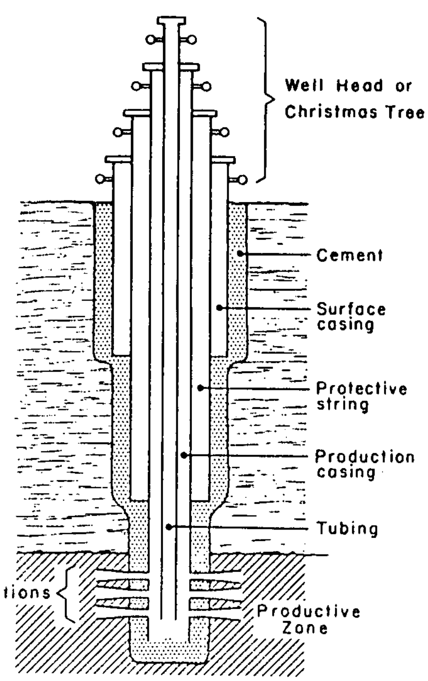
The number of shots expended may vary from one, or very few, to several hundred, depending on the nature of the formation and its contents. Practically all modern gas wells are completed by setting pipe through the pay section and perforating selectively to conduct the gas into the well.

Open-hole completions are advantageous when oil is contained in the rock under low pressures. In such cases, it is desirable for the oil to have as free access into the hole as possible.

The method of running and cementing casing is the same with all strings. As described in the chapters on *Methods of Drilling,* the casing is put into the hole in a manner similar to the handling of drill pipe. Cementing is done by forcing cement slurry down through the pipe and up and around the outside to fill the annular space. The cement is pushed down by a column of water or mud, sometimes with the aid of a plug, and held in place until it hardens.

Well Heads

On the surface, each string of casing is surmounted by a *bradenhead,* which is a device to permit control of the contents of the pipe. These heads are doughnut shaped and



Schematic shows arrangement of multiple casing settings and bradenheads

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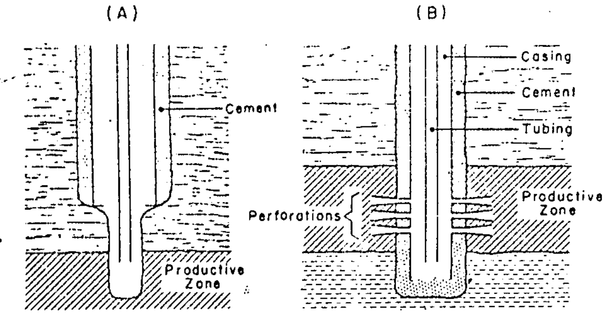


Open hole completion   Casing set thru productive formation

sized to fit both the casing to which they are attached and to close against the next pipe to be run. In this manner the space between nested casing is sealed and access established at the wellhead by valves.

The final head, usually called the *casing head*, is screwed or welded to the oil string and is capable of receiving the tubing. Valves and gages maintain control of, and access to, the annular space between the casing and the tubing as with the casing to casing contact.

The tubing is, likewise, topped by a *tubing head*. If the well flows, the top is blanked off and the flow directed through appropriate valves. In the case of a pumping well, a hole in the top is provided for the insertion of sucker rods and a stuffing box, for sealing, is added to close around the polish rod that is precision ground to reduce wear on the flexible sealing rubber as the rod moves up and down in the pumping cycle.

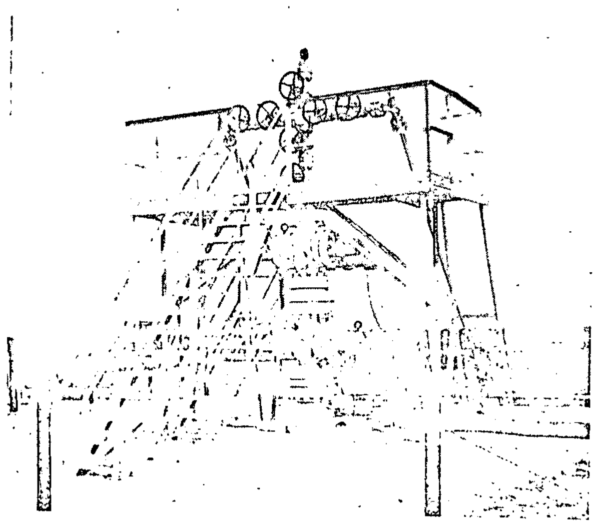
Upon completion, all of the heads are bolted together and, with their array of valves and gages, become a unit known as the *Christmas tree*. Reference to the accompanying illustration will supplement the explanation of the structure of this piece of equipment.

Determining Whether to Set Pipe

Obviously, all of the expenditure of setting casing will not be made unless there are sufficient indications that a commercial well can be made. The decision to complete a well is generally based on a careful study of data obtained from several sources.

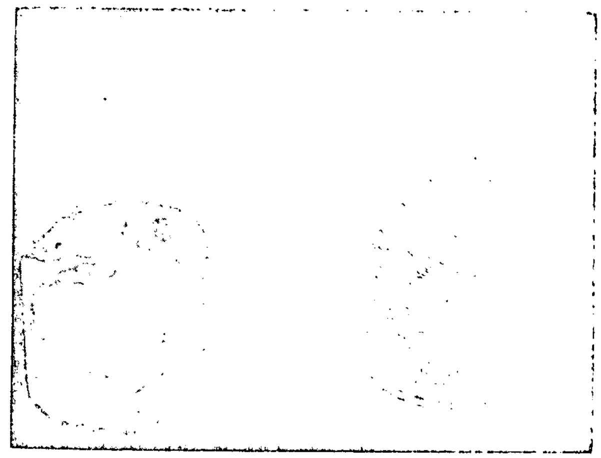
Cuttings and Cores

One of the primary sources of information on the progress of the well and its potentialities come from the samples


Christmas tree — consisting of high pressure flanges and valves to control flow of gas and oil from underground reservoir to surface.

of cuttings. As the rock is chipped away by the bit, the particles are carried by the mud stream to the surface where they are separated from the mud. At intervals, samples of these cuttings are taken for examination. The geologist is able to determine, by analysis, both the formation being drilled and, to some extent, the gas, oil or water content.

If the samples are not conclusive, but indicate possibilities, the rock may be *cored*. A special bit is used to leave a section of the rock standing in its hollow center (much like a biscuit cutter) as it drills ahead. This *standing core* is entrapped in a core barrel above the core bit and brought to the surface for analysis.


Cores. At left is sandstone, at right is shale. Both were taken from a Wilcox formation between 900 and 10,000 ft.

Often, the core is sealed in a special container and rushed to the laboratory immediately after being withdrawn from the core barrel. Trained scientists there subject the core to a number of tests to determine the relative gas/oil/water content, the porosity, and the permeability. The information, thus obtained, becomes the basis for estimates of the value of the minerals in place.

If drilling has progressed through a formation before it is decided that a core is needed, the sample may be taken by *side wall coring*. This is accomplished by lowering a cutting barrell into the bore hole on a wire line. Electrically detonated charges drive small cutting heads into the formation at desired points. Multiple cores may be secured this way. They are retrieved by raising the barrel, with its captive pendulant core catchers, to the surface.

Electrical Logging

In addition to tabulating the characteristics of the well bore from the cuttings, the well may be *logged* with electrical devices. For this purpose, electrodes are lowered into the hole and slowly withdrawn. A continuous recording device measures the relative resistivity of the formations to the flow of electrical energy flowing in a circuit around the electrodes. Measurement is also made of the "self-potential" or the ability of the formations to generate minute quantities of electricity.

Comparative experience with the results of such logs from hundreds of wells enables the geologist to interpret the results in terms of oil and water; shale, lime and sand. To date, no definite interpretation for the presence of gas is possible from the usual electrical log.

Resistivity and induction logging, just referred to, is done in the open hole. After pipe has been set, it is ineffective. But, the well can be logged electrically, through the casing, by measuring *radioactivity* to obtain similar results. The relative strength of gamma ray penetration is charted continuously as the sensitive electrode is slowly withdrawn from the hole. The resulting log is analyzed in much the same fashion as the more conventional log.

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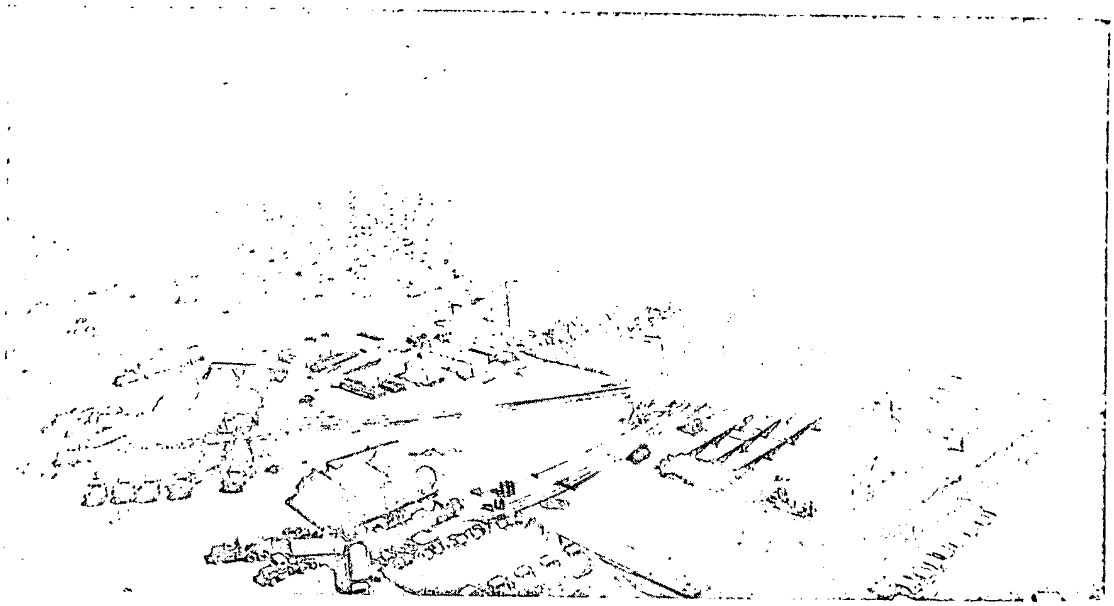

King-size fracturing job in process on potential gas and oil well. Note large amount of equipment required.

Gas Detection by Mud Analysis

The most successful method, at present, for detecting gas in the hole is the *gas "snifter" device.* Portable laboratories are set up on well sites and drilling mud is continuously examined as it returns from the bore hole. All of the mud characteristics are noted and any addition to the mud stream from the formation is detected. Very delicate instruments are capable of discovering the most minute quantities of gas. The depth of such gas is recorded, and careful comparison with other logs is made later.

Drillstem Testing

If a possible productive zone is encountered that is unevaluated, the operator may want additional evidence of the amount of gas or oil to be expected from the saturated formation. In such a case, a *drillstem test* may be taken. The bit is withdrawn and a special tool is run back into the hole on the drillstem just above the formation to be tested. This device has a section capable of expansion in such a manner as to seal or pack off all of the open hole above it from that portion directly below that is to be tested.

After the packer is set, the lower end of the testing tool may be opened to allow the entrance of gas or oil that may be coming from the formation. In some cases, the pressure is great enough to allow the gas, oil, or water to flow through the drillstem to the surface. If not, the amount can be calculated by closing the tool, to retain whatever it has entered; and, thereafter, withdrawing the pipe.

Counting the number of joints or "stands" of pipe that contain fluid and noting the characteristics of the contents gives an indication of the kind of well which may be expected. For comparative purposes, the amount of time the tool is allowed to remain open is recorded. This type of test is always run in the open hole.

Bringing in the Well

Having ascertained that there is a good chance of making a well, the casing is run and cemented. When the cement has set the well is ready for the final steps in completion. If the casing has been set on top of the pay, for open hole completion, it is now *drilled in* by drilling out the cement plug and penetrating the producing formation for the desired number of feet. If casing has been set through the pay zone, a perforating gun is run and holes made, as previously described, through the casing and cement and into the rock.

After contact has been established with the reservoir of gas or oil, either by open hole or through perforations, *tubing* is run into the well. Efforts are then made to start the well to flowing. Sometimes the well has sufficient pressure to bring the gas and oil to the surface as soon as it is opened up. If flow is established, the well may be tested by flowing at varying rates, through different sizes of orifice valve openings, to determine the most efficient volume of production with the minimum pressure drop. The amounts of pressure on both the tubing and casing are closely watched because of their importance in relation to the production of gas and oil.

Swabbing

If the well fails to flow, artificial means of stimulation may be required. The most common means of starting the well is by *swabbing.* A close fitting cylinder, resembling the traveling barrel of a pump, is lowered into the tubing by a wire line until it has fallen far enough into the fluid of the tubing to pick up an adequate load. Thereafter, it is rapidly withdrawn to carry above it an amount of fluid to the surface. A simple ball and seal valve retains the load of liquid above the swab on the outward trip but permits the tool to drop easily through the fluid.

The swabbing process reduces the height of the column of fluid and thus reduces the pressure exerted by the column on the formation at the bottom of the hole. Although the level of the fluid may not be lowered, it may be lightened by the removal of water and mud that may have remained. The swab also creates a semi-vacuum, as it rushes up the tubing, to further stimulate the movement of gas or oil into the well from the formation. From a few strokes to many days of swabbing may be necessary to clean up the hole and start the well to flowing on production.

Shooting, Acidizing and Fracturing

In some cases even the swab may not be enough to induce the well to produce due to the denseness or *tightness* of the formation. In earlier days, wells were loaded with nitro-glycerin that, on detonation, so shattered the formation as to cause gas and oil to enter the hole readily. In addition to the danger to life and the bore hole, there were frequently costly clean-out jobs required for removing the debris accumulating from the explosion. Consequently, other methods have largely replaced this type of *shooting.*

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In limestone, inexpensive acids were found to be effective in opening the formation. From a few to several thousand gallons of acid are forced into the formation under pressure. The calcareous portions, being soluble in the acid, are removed and blown out at the surface by the *acid gas* created or by movement with the fluid as the well flows or is swabbed. Many prolific fields have been brought into production by this means.

A safer and more effective way of *fracturing* the rock is the pumping of liquids under extremely high pressures into the formation. Usually the pressures involved are in excess of those used in acidizing and will reach 15,000 psi or higher. The liquid employed for the job is usually crude oil with good flow qualities. The crevices opened by the pressurized fluid are generally longer, more narrow in width, and more numerous than those developed by nitro shooting.

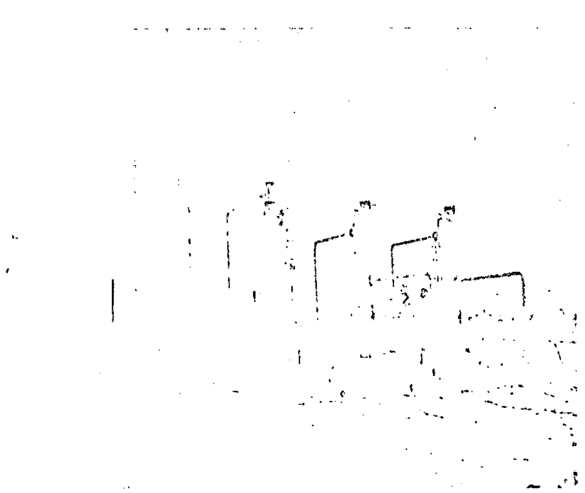
Once the fracture has been made, it may close as the liquid is withdrawn. To prevent this and to establish permanent permability, round grains of sand are entrained with the fracturing fluid. This sand, in suspension, is readily conveyed into the fractured stratum with the fluid being pumped in under pressure. By withdrawing the fracturing liquid slowly the sand grains are entrapped to remain in their advance positions as "props" along the fracture planes. Much like miniature mine columns and cribbings, the sand grains hold avenues open for the traffic of gas and oil flowing to the well for production.

Packers and Squeezing

When it becomes desirable to put pressure on the formation through the tubing, without extending the pressure to all parts of the casing, a *packer* is used. This is the same device described for use in drillstem testing except that it is used inside the casing to close the *annulus* between the tubing and the casing. Thus, two spaces are segregated so that different pressures may be developed and contained within them as though they were separate vessels. This is an important aid in performing many of the tasks required in good well completion. Packers are frequently employed in acidizing, fracturing, and in squeezing.

This last operation is usually a remedial action. If the gas-oil ratio is too high — that is, if the volume of the desired product is too great in relation to the other — the section containing the less desirable petroleum phase is *squeezed off*. Or, salt water may be entering with the gas or oil and steps are required to stop its admixture.

Squeezing is accomplished by one of two techniques. Either all of the perforations are cemented closed, or packers are set in such a manner as to restrict the section of the



Gas and oil separators. This is a three-stage separation installation. In background, left, are stock tanks.

stratum open to the flow of cement through the tubing. In the former case, new perforations must be made for both the squeezing of cement, under high pressure, into the undesirable portion of formation and for subsequent contact with the selected section for production.

The net result is the same — cement, under high pressure, enters and blocks that portion of the stratum that is producing unwanted water, gas or oil. Perforations are opened, or remain open by virtue of packer settings, to the valuable zone through which the unadulterated product will flow if the squeezing or sealing has been properly done.

Pumping Wells

All commercial gas wells flow by virtue of the qualities of gas. However, gas may be depleted and the well may begin producing oil when both have been present in the reservoir. When oil can no longer be brought to the surface by the differential pressures (those existing in the formation opposed to atmospheric pressure plus the weight of the column to be lifted) it is necessary to resort to *secondary recovery*. This, ordinarily, involves pumping the well.

Solid rods, called *sucker rods*, are run down inside the tubing to activate, by an up and down motion, the working barrel of a pump near the bottom of the well. The working barrel of the pump moves snugly inside a machined barrel fixed in the tubing string. In the bottom of the cylinder is a simple ball and seat valve, called the *standing valve*, fixed in a cage. A similar valve, placed in the moving barrel, combines its action with the lower valve to permit a quantity of oil to be lifted on each stroke of the pump.

Movement is imparted to the sucker rods and the pump by a lever and fulcrum device variously referred to as the *pump jack, walking beam or pumping unit*. Essentially, a pivoted steel beam is balanced with the weight of the sucker rods and fluid load on one end and balance weights on the other. A relatively small amount of power is needed to move the beam up and down to pump the well. The rods are fastened to the end of the beam, over the wellhead, with a flexible cable.

Surface Equipment

At the surface, *flow lines* connect the crude products of the well to the initial vessels for their treatment and temporary storage. Gas and oil produced together are conveyed through a *separator*, which delivers the gas, free of oil, to lines for subsequent processing. The oil goes to tanks, on the lease, for holding until it is measured out into the pipelines.

Traps are provided in the flow lines from gas wells to extract any liquids that may be in the gas. These *traps or drips* are designed so that changes in velocity and temperature aid in drying the gas before it is metered. The trapped liquids are drawn off either manually or automatically.

There are numerous other types of equipment for the preliminary cleaning of gas at the wellhead, such as scrubbers, but they all bear so much resemblance to the processing equipment to be discussed in this series that it is sufficient, at this point, to recognize their existence only. The purpose of drips and scrubbers and such devices is to clean the gas before delivery into the pipelines but the tendency has been to do less such extraction at the wellhead and more at the processing plant. In the past, many valuable elements were lost by wasteful initial treatment. Now, as will be seen in subsequent chapters, everything of economic value from gasoline to sulfur is taken from the gas before it passes on for consumption as "dry" gas.

Acknowledgment

This chapter on "Completing the Gas/Oil Well" was prepared by W. K. Powell, president, Beard Drilling Company, Inc., Duncan, Oklahoma. ★ ★ ★

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No. 26

Tunnel Sewer Construction Facilitated by Special Pipe

Exemplified in Two Ontario Jobs

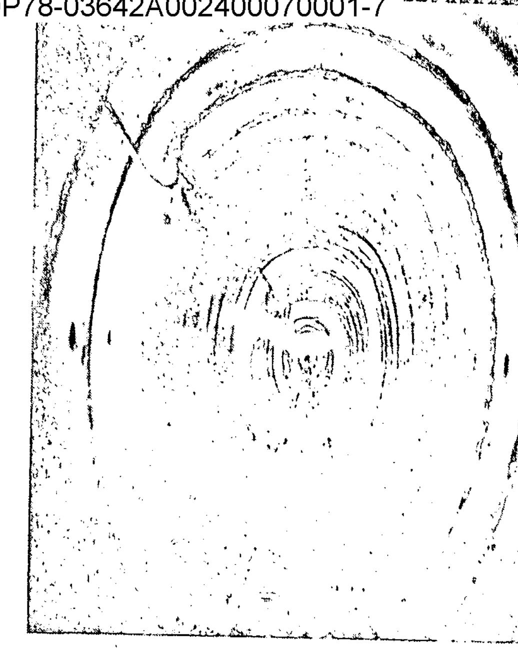
At two points in Ontario — in the city of Toronto and in Crowland Township near Welland — a new method of sewer construction is under way. It is especially adapted to sewer work in built-up areas.

The city of Edmonton, Alta., pioneered the use of the method in Canada on a day-labor job, but the two Ontario projects are the first in Eastern Canada on which the new technique has been used, and only the second and third of the kind in the country.

The new method employs pipe known as Inner Circles Tunneliner; in Eastern Canada the pipe is manufactured and sold by Niagara Concrete Pipe Ltd., St. Catharines, Ont. The technique involved makes it possible to pass full-ring, precast concrete pipe through the portion of conduit already laid. This is due to the elliptical shape of Inner Circles pipe and the ratio of laying length to width.

In the Toronto job, the tunnel method of construction was selected by the Department of Works of the city of Toronto because the street involved, Elizabeth St. south of College St., is a narrow thoroughfare at the rear of two hospitals. It was considered desirable that traffic disruption and noise be kept to a minimum; furthermore, borings had indicated that the sewer would be constructed in a plastic blue clay which would be self-supporting.

The design dictated the use of a 33-in.-diam. pipe, and if the conventional monolithic method of tunnel construction had been adopted, the minimum size of tunnel for practical purposes would have been 54 in. Because such a tunnel would have been uneconomical Inner Circles pipe was selected by Clement Edwards, city engineer at that time, and D. F. McCarthy, sewer engineer.

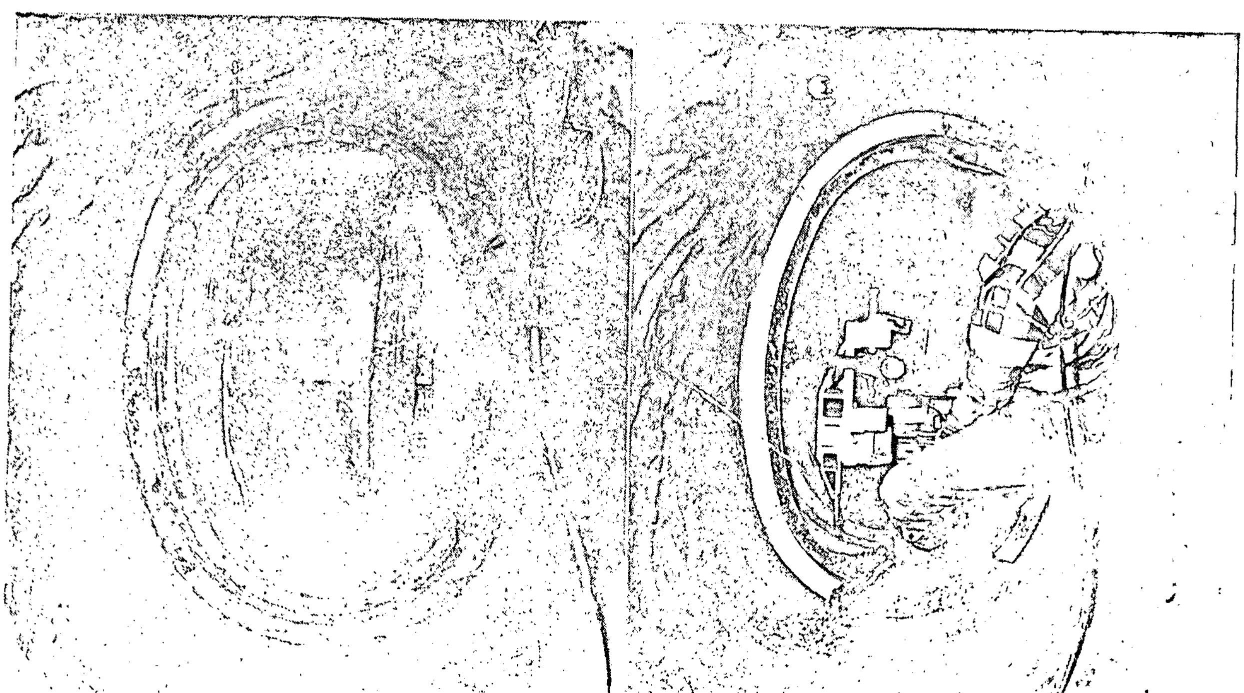


A sewer in Toronto constructed in tunnel, using Inner Circles Tunneliner pipe.

Under a contract awarded to Dundas Construction Co. Ltd., Toronto, shaft sinking commenced in mid-November. The length of the sewer was 1300 ft. and the average depth to the invert is 27 ft.

On February 18, the city of Toronto awarded to Alcan-Colony Ltd. a contract for another project which in-

(Continued on page 53)



Left: Showing how Inner Circles Tunneliner pipe rings are transported through sewer already completed. Right: The Tunnelugger machine for delivering and positioning the pipe rings.

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REPORT OF A.W.W.A. CONVENTION

(Continued from page 31)

using equipment in laundries and large industries. It appears, however, that the customer is likely to create problems within his own premises which he must correct with air chambers and surge-suppressing equipment. It would seem there are few, if any, reported examples of water hammer failures in mains due to causes on customer premises.

Controlling Reservoir Evaporation

On the subject "Reservoir Evaporation Control," Lloyd O. Timblin, Jr., W. T. Moran and W. U. Garstka, all of the Division of Laboratories, Bureau of Reclamation, Denver, Colo., presented a paper which elaborated on tests based on the fundamental studies of Rideal, Langmuir, Schaefer, LaMer and others, and the early field studies of Mansfield, which have shown that monomolecular layers of certain materials such as hexadecanol might be advantageously used for reservoir evaporation reduction.

The paper mentioned that well over 100 outdoor screening tests with standard Class A evaporating pans were made with different monomolecular and duplex films. Under these conditions hexadecanol consistently was one of the better performers. However, the efficiency showed much variation depending upon the supplier, method of application, form of the material, and ambient condition. A maximum of 64% was observed. Pilot studies were also conducted with hexadecanol on pools 33 x 10 ft. Preliminary toxicity studies with hexadecanol indicated that no gross toxicity effects to the biological elements of a reservoir would result from a short application of hexadecanol.

Preliminary arrangements, the paper explained, were made for a full-scale evaporation reduction to be made on Lake Hefner, Oklahoma City. To establish that a treatment with hexadecanol would not cause a deterioration of water quality, tests were made on nearby Kids Lake. The results of a 2-month treatment on Kids Lake indicate that from the standpoint of domestic water there would be no deleterious effects upon the water quality by an application of hexadecanol.

Field tests are currently under way to develop techniques for application and maintenance of a monomolecular layer of hexadecanol on a large reservoir. Methods of film detection and evaluation are also being field-tested.

Controlling Rainfall Artificially

An A.W.W.A. Task Group report on "Weather Modification", presented by Burton S. Grant, assistant general manager and chief engineer, Department of Water and Power, Los Angeles, Calif., presented a picture of current professional opinion on the subject of weather modification. The author quoted Dr. Arnold Court of the University of California, to the effect that (a) to evaluate cloud-seeding operations, the exact purpose and method of evaluation must be stated beforehand; (b) with present equipment, total rainfall over an area cannot be estimated with sufficient accuracy to permit detection of the order claimed by most operators; and (c) because weather-modification procedures inevitably modify all aspects of rainfall — duration, intensity, drop size, and accompanying winds — which in turn affect the accuracy of the raingage, some apparent increases in rainfall could actually be increases in raingage catch, caused by decreases in rainfall intensity or in wind gustiness.

"The two processes of precipitation development," the report stated, "one involving cloud droplets, the other depending on the growth of ice crystals, may sometimes be speeded up by suitable seeding techniques, and some clouds may therefore be induced to precipitate which might not otherwise have done so, at least not immediately. Whether this is possible depends on the cloud structure, however, and the structure cannot be modified. Because weather modification applies only to favorable cloud formations and results chiefly in speeding up precipitation, weather modification would be more correctly considered a redistributing of precipitation."

•

TUNNEL SEWER CONSTRUCTION

(Continued from page 29)

cludes about 500 ft. of 39-in.-equivalent Inner Circles pipe.

The Crowland Township job, designed by Graham Reid & Associates Ltd., consulting engineers, Toronto, and being carried out by Dick Construction & Engineering Co. Ltd., Welland, Ont., started on December 1. It calls for 2,300 ft. of 36-in.-equivalent and 1,700 ft. of 54-in.-equivalent Inner Circles, this pipe being chosen because

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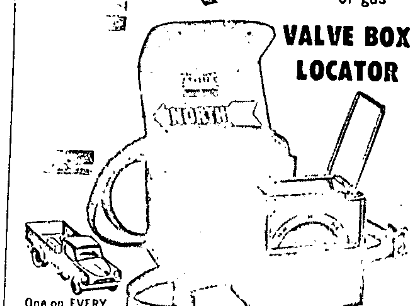

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estimates showed that monolithic tunnelling would be more expensive.

The engineer's decision was again based on three very important considerations: (1) to keep busy streets from being dug up, (2) to keep construction noises to a minimum, and (3) to take advantage of the existing plastic clay soil in which this method of construction has proved to be most economical.

The "Tunnelugger"

The new method features the use of a machine known as the "Tunnelugger" which is electrically-powered and runs on tracks. Its function is to quickly deliver and position Inner Circles at either end. The "Tunnelugger" is also available for hauling mucking carts in and out.

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"In the new process," the manufacturers of Inner Circles Tunneliner say, "there are no delays for mining shifts, no time wasted setting forms or bracing finished work. The method is so simple that any qualified contractor can bid on it with confidence.

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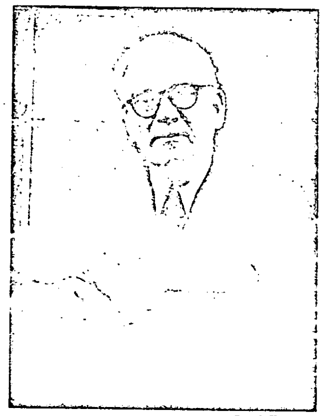
No. 21

SCIENCE AND TECHNOLOGY

FORTUNE, Sept., 1951

HORIZONTAL DRILLING

LEO RANNEY HAS A BOLD NEW STRATEGY FOR WORKING UNDERGROUND. HIS MEDIA ARE OIL, WATER, SHALE, COAL, SALT, AND CITY PAVEMENTS



Frank H. Bauer

THE INVENTOR, Leo Ranney, is a careful student of geology and a former Standard Oil engineer. He has been called a dreamer for his unorthodox ideas on oil, coal, and shale but no one denies he has made the only real improvement in water-well design in millennia.

In the endless search for new supplies of oil and water, the ideas of Leo Ranney may prove to be more important than those of any other man alive. For forty years this Iowa-born engineer has devoted his energies to a basic revision of the processes of underground extraction. While most twentieth-century inventors have labored on the recondite frontiers of science, Leo Ranney has seldom borrowed from anyone later than Isaac Newton. Thus his ingenious proposals have a homely appeal for the harassed layman who has not really understood any major invention since Edison came up with the motion-picture machine in 1891.

On these pages are illustrated some of the results of Leo Ranney's four decades of subterranean study and invention. His fundamental observation is that nearly everything man wants to do underground can be reduced to a problem of drilling holes (not tunneling)—and that for almost every purpose a horizontal hole is better than a vertical one. Therefore, the basic art developed by Mr. Ranney is a method of drilling carefully controlled horizontal holes for great distances through the earth. And wherever possible he prefers to work entirely from *above* ground. Mr. Ranney's method for the underground gasification of coal, which could make lump coal a laboratory curiosity, was pictured in the April FORTUNE. But this is only one of many possible applications for horizontal drilling. Thus, among other things, he proposes to recover oil with great efficiency (see facing page), to provide cities with a bombproof water supply (page 98), to project pipes under busy streets (page 100), and to drive oil out of North America's vast shale beds (page 101).

RANNEY'S HORIZONTAL OIL WELL

To extract the last drops of oil out of the earth, Ranney proposes to sink a small work chamber in an oil formation, and from there drill horizontal drainage holes, about eight inches in diameter, as far as a mile out into the sand (only first 100 feet need be piped). Oil can then seep into the holes and flow by gravity to the central chamber, whence it is pumped to the surface. In this way Ranney hopes to retrieve a fair portion of the 100 billion barrels of U.S. oil now classed as "unrecoverable" because there remains no pressure to force the oil into vertical-type wells. (The nation's proved, or "recoverable," reserve is only 21 billion barrels, barely enough for twelve years at going rates.) By repressuring and water-flooding, some of the "unrecoverable" oil can be forced out; but about half is left behind. To speed up the flow in his system, Ranney can use alternate spokes for heating and applying pressure (possibly by burning a small portion of the oil *in situ*) and thus drive even the most viscous crudes into the unheated holes. He might even vaporize the crude and boil it right out of the earth.

So far only the Ranney water collector is on a commercial basis, it having won prominence during the war for supplying tremendous volumes of pure, iron-free water (peak capacity 600 million gallons a day) to some of the great ordnance plants. The Ranney oil well has not moved much beyond the experimental stage, but with demand for crude exceeding even the wartime peaks it seems only a matter of time until the producers will be forced to try out horizontal drilling on a commercial scale. The conduit-laying proposal has excited the interest of one of the nation's largest utilities and the work is going forward. As to oil shale, Ranney has generated considerable enthusiasm among petroleum engineers, particularly in the Canadian industrial center of Sarnia, where Imperial Oil runs a 45,000-barrel-a-day refinery and the Polymer Corp. operates the British Empire's only synthetic-rubber plant—both almost wholly dependent on the U.S. for petroleum feed stocks. The irony is that Imperial and Polymer Corp. lie directly over a rich bed of shale that might yield some 15 billion barrels of oil—equivalent to three-fourths of the entire proved crude-oil reserves of the U.S.

Leo Ranney's suggestions for coal constitute a chapter in themselves. Briefly, Ranney, as long ago as 1929, proposed methods of (*a*) removing the valuable free methane from coal seams, and (*b*) burning coal underground to remove the energy in the form of gases. Pittsburgh Consolidation Coal (FORTUNE, July) has a contract with Ranney to run a methane-recovery experiment; and both Pitt Consol and Standard Oil are studying underground gasification as a possible route to synthetic gasoline.

After graduating from Iowa State Teachers' College in 1905, Leo Ranney spent two years in the public schools of Alaska. There he heard the tales of many an old prospector and became fired with an ambition to study geology. He returned to the States and obtained a B.S. in geology at Northwestern and then took some courses in engineering at Columbia. During the first world war he served as a special assistant to the Army Chief

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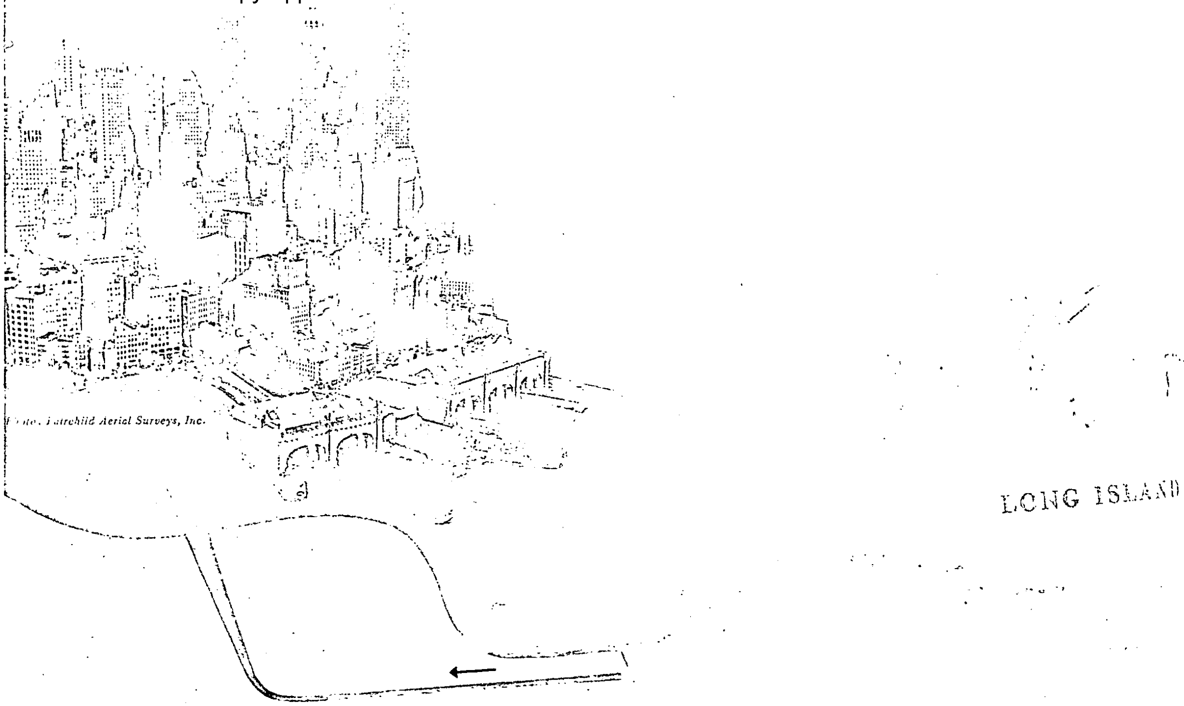
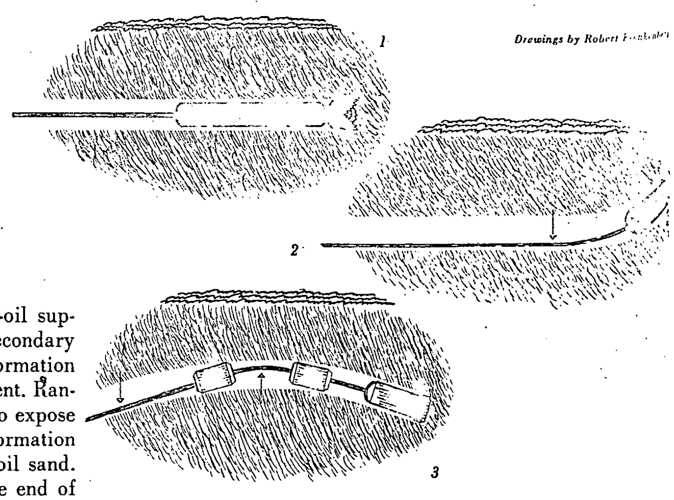


Photo, Fairchild Aerial Surveys, Inc.

A BOMBPROOF WATER SUPPLY

New York City obtains most of its 1.1 billion gallons a day of water from vulnerable surface reservoirs. To provide a measure of security in a bacteriological or atomic war, Leo Ranney has suggested to the Army that New York could draw on Long Island for a vast bombproof reserve of water. "Long Island," says Ranney, "is just a vast sand dune that soaks up rain water like a sponge." And the island catches a copious share of rain—over one trillion gallons (43 inches) a year. Most of this sinks into the ground and is wasted to the sea. By installing a battery of the highly efficient horizontal water collectors that he invented in 1933, Ranney believes he could easily pump half a billion gallons of water a day into New York without depleting the supply.



Drawings by Robert Frankenberg

of Ordnance, who, becoming worried about the crude-oil supply, asked Ranney to make a study of methods of secondary recovery. At that time wells sunk into an oil-bearing formation usually recovered only 10 to 20 per cent of the oil present. Ranney decided the best way to get the remaining oil was to expose a greater area of the oil sand by tunneling under the formation and drilling a number of short wells upward into the oil sand. (He had not yet developed horizontal drilling.) At the end of the war he tried his method in Texas and filed patent applications. By 1925 the country was in the grip of an oil-shortage panic and Standard Oil bought up Ranney's patents, making him President of Ranney Oil Mining Co., a Standard subsidiary. Just as he began to think his fortune was assured, several large new fields were discovered in California and Oklahoma. And a short while later fabulous East Texas came gushing in, crude dropped to 10 cents a barrel, and Standard had oil running out of its ears. Thereupon Ranney arranged to dissolve his ties with Standard so he could try peddling his method to the industry at large. "It was during the depression," he says, "that I learned I was no salesman." Forced to cut the cost of his method, Ranney perfected the art of horizontal drilling and substituted it for hand-driven tunnels. But still there were no takers.

PRECISE DIRECTIONAL CONTROL is the heart of Ranney's subterranean technique. To go straight (*figure 1*), he mounts a long rigid core barrel behind the rotating bit. To guide his bit up (*figure 2*), he uses the sagging drill rod as a lever. To go down (*figure 3*), he inserts two guides to support the rod and make the bit dip. To curve right or left (*figure 4*), Ranney uses a finned gadget that crawls in the direction of bit rotation. He is now perfecting a remote-control, omnidirectional system. Cuttings are washed out of the hole conventionally (*figure 5*), by circulating mud down the center and back around the outside of the drill rod.

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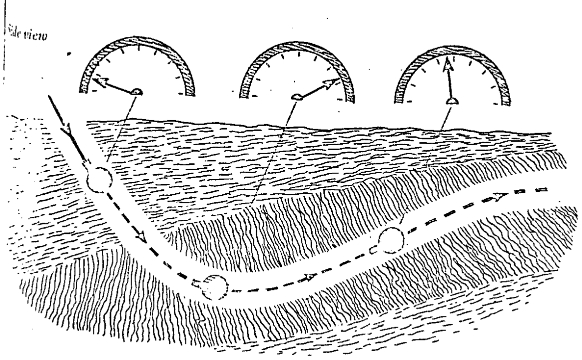
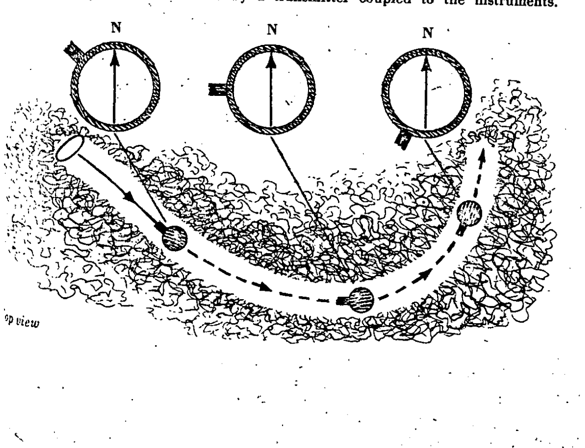


'HE **EXACT PATH** followed by a "horizontal" hole can be plotted by taking ᴑ basic fixes at regular intervals: the depth, and the angle of the course with spect to north. To determine depth (*top*), a water-filled tube carrying a pressure auge in its nose is pushed through the hole. The gauge indicates the head of water, ace depth, at any point. Similar check points for course (*below*) are obtained by assing a magnetic or gyrocompass through the hole. The readings may be recorded n film or relayed to the surface by a transmitter coupled to the instruments.



It was then Ranney recalled something his wife had said to him in 1929: "Not everyone needs oil but everybody needs water every day." Temporarily discouraged on oil, Leo Ranney saw immediately that his basic oil well (page 96) should make an excellent water well. The only change necessary was to replace the horizontal holes with perforated steel pipe to hold back the gravel present in the typical water-bearing formation. He had just finished his designs when he chanced to read in the *Illustrated London News* that London was suffering a severe water shortage. This was 1934. Ranney sailed for England immediately and found he was enough of a salesman to swing the conservative Metropolitan Water Board. Within six weeks the first successful Ranney water collector was producing the specified two million gallons a day of pure water. (It is still flowing at that rate.) At the age of fifty, Leo Ranney had demonstrated the first radical improvement in water-well design in several thousand years, and got a long-deferred taste of success.

Ranney followed the London installation with one in Lisbon, and then took his idea to Paris, where a competition had just been held to find the best system for supplying the city with a billion gallons of water a day. Ranney arrived after the award had been made but he quickly drew up a plan of his own that looked so good the authorities substituted it for the one already selected. Paris started work on the $20-million project, but called the whole thing off when war appeared imminent.

Back in the U.S., the Ranney Water Collector Corp. of New York was created just in time to supply many of the most vital war plants with emergency supplies of pure filtered water. Using Ranney's system, the great Indiana Ordnance Works near Charlestown was in production by July, 1941, only six months after ground was broken. A conventional water-treating plant to supply the same quantity of water would have taken a full year to design and build and would have cost $5 million more than

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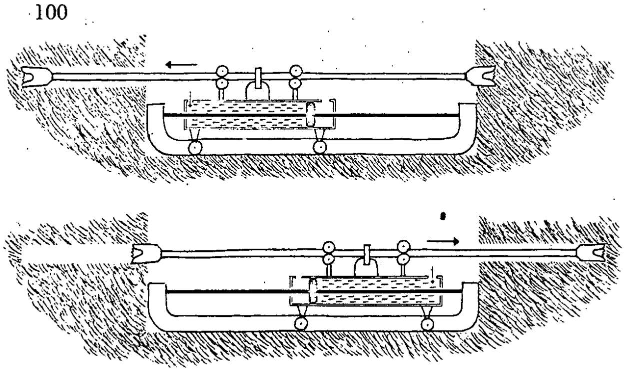
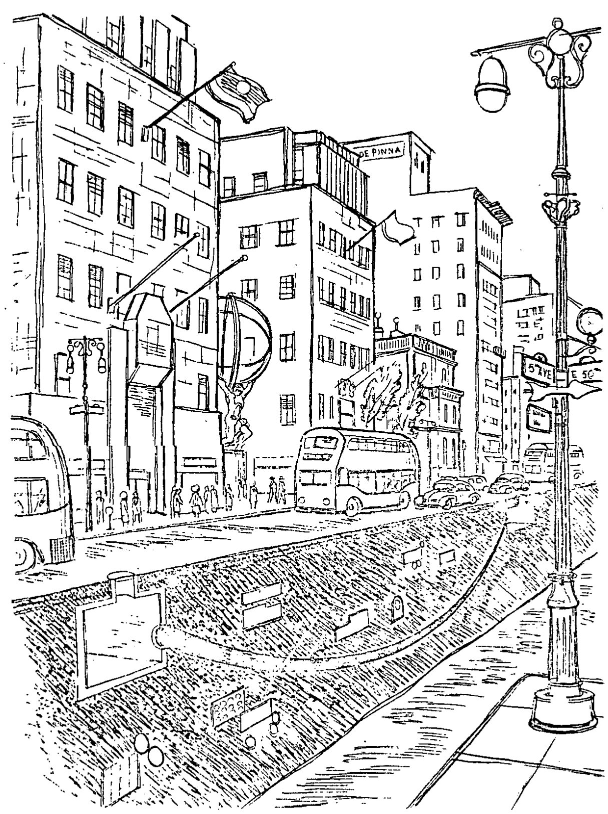


THE HORIZONTAL DRILLING MACHINE

With Ranney's machine (*above*), two opposed holes can be drilled out alternately by pumping hydraulic fluid from one side of the sliding cylinder to the other and adding sections of drill rod as the holes lengthen. This is Ranney's technique for boring horizontal oil wells. When drilling from above ground the machine is tipped at an angle. A single hole can then be driven down, leveled out (as in shale, *facing page*), and after running a mile or so, be tipped up to return to the surface. In the Ranney water collector no drilling is needed. Perforated steel pipes, bullet-nosed, are jacked out from a caisson and penetrate 250 feet into the aqueous stratum.



AN END TO TEARING UP PAVEMENTS

The ingenious application of horizontal drilling sketched above has one of the nation's largest utilities greatly excited. Laying new subsurface cable and pipe in any large city has become a costly engineering problem and a severe community nuisance. Traffic gets fouled up, and the utility doing the job always runs into a barrage of litigation. In New York City alone torn-up pavements inspire an average of six lawsuits a day. To eliminate all this, Leo Ranney envisions holes drilled from manhole to manhole, which could, if desired, loop far below the existing snarl of subsurface impedimenta. He also proposes to run pipelines under rivers in similar fashion.

Ranney's collectors. Other wartime users included Allied Chemical & Dye, Air Reduction, and Seagram & Sons. The number of units in the country today has passed seventy.

During the war Leo Ranney served as a consultant on oil for the Australian Government. (A month before Pearl Harbor he turned down a highly attractive three-year contract proffered by the Japanese Government.) At Lakes Entrance, 150 miles from Melbourne, Ranney supervised the design of his largest horizontal oil-well system with a drilling chamber at the base of a 1,156-foot shaft. Uncompleted when the war ended, the project passed from government to private hands, and work on the horizontal well is again going forward. While in Australia, Ranney also drew up plans for the removal of methane from a gassy colliery under Sydney. The gas was compressed and used as a substitute for gasoline in Army trucks and other vehicles throughout the war.

It is a curious reflection on America's vaunted industrial leadership that several of Leo Ranney's ideas have received their first test in foreign countries. (Even underground gasification of coal made its debut abroad, in Russia, and Ranney suspects that the Russians made liberal use of the patent applications he sent to Moscow and never heard from again.) Part of the explanation may be that American industry tends to suspect any idea that can't boast an immaculate conception—paternity anonymous—in one of its own giant research mills. Industry is obviously wary of a private inventor with a broad-gauge idea who can talk big money in either patent rights or royalties (and Ranney's ideas touch two of the industrial colossi: oil and coal). With his water collector Ranney didn't encounter this obstacle. He had a method at once remarkably efficient and remarkably cheap (less than $100,000 per collector of ten-million-gallon-a-day capacity), which produced a substance of slight negotiability. It isn't so easy for Ranney to prove his case with oil. And his critics are fairly vocal. They dispute Ranney's whole thesis that horizontal wells are much better than vertical wells for extracting the final 50 per cent of residual oil in the earth. But Ranney insists that until someone actually drills 100,000 feet of horizontal holes through a single square mile of oil sand, no one can predict what will happen. (The amount of sand exposed by the most closely spaced vertical wells seldom exceeds 10,000 feet.) Now that crude is tighter than ever before in history, Ranney should soon have his day in court.

The inertia in the coal industry has been something else again. When Ranney talked coal any time between 1925 and 1940 he was talking to and about a distressed industry, which reckoned its research in nickels and dimes. Today, Pittsburgh Consolidation, Standard Oil, and Dobie Keith are all driving hard on coal, and Ranney at last has the attention of some engineers with considerable vision of their own.

At sixty-three, Leo Ranney is still discovering new uses for his versatile horizontal techniques. For instance, he believes he can extract hydrocarbons from the multibillion-barrel tar sands of California and Alberta, or work certain salt deposits (such as the table salt and potash salts of New Mexico and Saskatchewan), or improve the efficiency of prospecting for metallic ores by pulling out long horizontal cores for analysis, or even mine coal —either as a powder or in old-fashioned lumps—from *above ground*, at ten or twenty times present efficiency, by tricky modifications of his drilling machinery. If only a fraction of his proposals reach maturity and commercial application, Leo Ranney will be recorded as one of the most ingenious minds of this age.

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